THE

GEOLOGICAL MAGAZINE.

VOL. LXXIII OF WHOLE SERIES.

JANUARY—DECEMBER, 1936.

THE
GEOLOGICAL MAGAZINE.

VOL. LXXIII OF WHOLE SERIES.

JANUARY—DECEMBER, 1936.

THE

GEOLOGICAL MAGAZINE

OR

Monthly Journal of Geology.

WITH WHICH IS INCORPORATED

THE GEOLOGIST.

FOUNDED IN 1864 BY THE LATE DR. HENRY WOODWARD, F.R.S.

EDITED BY

R. H. RASTALL, M.A., Sc.D.

AND

O. M. B. BULMAN, A.R.C.S., Ph.D.

ASSISTED BY

PROFESSOR W. S. BOULTON, D.Sc.
PROFESSOR W. G. FEARNSIDES, M.A., F.R.S.
SIR T. H. HOLLAND, K.C.S.I., D.Sc., F.R.S.
PROFESSOR O. T. JONES, M.A., D.Sc., F.R.S.
PROFESSOR C. E. TILLEY, PH.D.
PROFESSOR W. W. WATTS, Sc.D., LL.D., M.Sc., F.R.S.
HENRY WOODS, M.A., F.R.S.
SIR ARTHUR SMITH WOODWARD, LL.D., F.R.S.

VOL. LXXIII OF WHOLE SERIES.
JANUARY—DECEMBER, 1936.

Reprinted 1966 for
WM. DAWSON & SONS LTD.
LONDON
with the permission of the publishers

Originally printed by Stephen Austin and Sons, Ltd.
Reprinted by Stephen Austin and Sons, Ltd., Caxton Hill, Hertford, England.

1127.5

CONTENTS OF VOLUME LXXIII, 1936.

No. 859. JANUARY. PAGE

S. W. WOOLDRIDGE and J. F. KIRKALDY. River Profiles and Denudation-Chronology in Southern England . . . 1
D. BALSILLIE. Leucite-Basanite in East Lothian . . . 16
O. M. B. BULMAN. *Rhaphidograptus*, a new Graptolite Genus 19
W. PULFREY. Geology of an Area in Kenya Colony . . . 26
C. S. PICHAMUTHU. On Bababudanite 39

REVIEW.—British Regional Geology, 45.
CORRESPONDENCE.—Lincoln Dryden, 47.
ANNOUNCEMENT.—48.

No. 860. FEBRUARY.

E. S. HILLS. Reverse and Oscillatory Zoning in Plagioclase Felspars 49
W. J. ARKELL. Tectonics of the Purbeck and Ridgeway Faults 56
A. ALLISON. Tertiary Dykes of Craignish, Argyll. . . . 73
H. G. SMITH. The South Hill Lamprophyre, Jersey . . 87
J. P. T. BURCHELL. Late Glacial Episode in the Thames Valley 91

REVIEWS.—Geology of Spitsbergen, 92; An Undiscovered Coalfield, 93; Tectonic Essays, 94; Geology of Greenland, 96.

No. 861. MARCH.

W. J. ARKELL. Tectonics of the Purbeck and Ridgeway Faults (*continued*) 97
R. W. BROCK (the late). Notes on the Pre-Cambrian of the Canadian Shield 119

REVIEWS.—A Book of Minerals, 141; Geology of North Wales, 141; Geology of Bristol and Gloucester, 142.
REPORTS AND PROCEEDINGS.—Mineralogical Society, 143; Geological Society of London, 144.

No. 862. APRIL.

W. O. WILLIAMSON. Some Minor Intrusions of Glen Shee, Perthshire 145
T. S. WESTOLL. The Dermal Ethmoid Shield of *Osteolepis* (Plates I and II) 157

PAGE

M. MacGregor. A Xenolithic Pegmatite in the Dalbeattie "Granite" 171
A. T. Hopwood. Earth-Movements, Ice Ages, and Faunas . 185

Reviews.—Physical Geology, 189; Molasse Sandstones, 189; Corundum in S. Africa, 190; The Klerksdorp Area, 191.
Correspondence.—B. Rama Rao, 192.

No. 863. May.

E. L. Bruce and W. Jewitt. Heavy Accessories of certain Pre-Cambrian Intrusives 193
E. S. Hills. Endocranial Structures in *Coccosteus* (Plate III) 213
J. J. Hartley. The Igneous Rocks of Slieve Gallion . . 226
A. Holmes. The Idea of Contrasted Differentiation . . 228

Reviews.—Stratigraphical Palaeontology, 238; Geology of Palestine, 239; Minerals for Beginners, 240.
Notice.—International Conference on Quaternary Research, 240.

No. 864. June.

W. N. Benson and R. A. Keble. Ordovician Rocks of New Zealand 241
C. T. Trechmann. The Basal Complex in Jamaica . . 251
E. B. Bailey. The Newry Igneous Complex . . . 267
O. M. B. Bulman. The Structure of *Oncograptus*. . . 271
H. H. Simpson. *Anthraconauta* in the Denbighshire Coalfield 278

Reviews.—Geologie von Europa, 380; Petrology of the North Sea, 283; Copper Resources of the World, 284.
Reports and Proceedings.—Mineralogical Society, 285
Correspondence.—A. E. Trueman, 287; J. Hanson-Lowe, 287.

No. 865. July.

A. F. Foerste (The late) and I. H. Cox. Cephalopods from Akpatok Island (Plate IV) 289
S. J. Shand. Rift Valley Impressions. 307
C. E. Tilley. Enderbite 312
P. E. P. Deraniyagala. Vertebrate Fossils from Ceylon . 316
Petrographic Nomenclature (B.A. Committee) . . . 319

Reviews.—Water Supply, 325; Tertiary Faunas, 326; Invertebrate Paleontology, 326; The Geological Map, 327; Mesolithic Settlement, 327.
Reports and Proceedings.—Mineralogical Society, 328.
Correspondence.—R. M. Brydone, 329; E. J. Wayland, 330; C. A. Matley, 331; L. L. Fermor, 333; L. F. Spath, 334; A. Holmes, 334; C. S. Pichamuthu, 335.

No. 866. AUGUST. PAGE

D. L. REYNOLDS. The Two Monzonitic Series of the Newry Complex (Plate V) 337
J. PARKINSON. Notes on the Petrology of the Gadabursi Country, British Somaliland (Plate VI). 365

REVIEWS.—Swedish Basalts, 378; Platinum Metals, 378; The Loos-Hamra Region, 379.
CORRESPONDENCE.—C. T. Trechmann, 382; J. Parkinson, 383.

No. 867. SEPTEMBER.

JAMES WRIGHT. New Scottish Carboniferous Crinoids (Plates VII–X) 385
E. B. BAILEY. The Ballachulish Lag. 412
J. A. BARTRUM. Spilitic Rocks in New Zealand (Plate XI) . 414
Dr. BERNARD SMITH (The late). Raised Beach at Brighton . 423

REVIEWS.—Road Aggregates, 427; Type Fossils, 427; Practical Photo-Micrography, 427; Geology of Europe, 428; Mineralogy, 429; Geological Survey of India, 429; Cambrian Faunas of Australia, 430; *Paradoxides* Beds of Öland, 431.
CORRESPONDENCE.—J. B. Scrivenor, 432.

No. 868. OCTOBER.

L. F. SPATH. So-called *Salterella* from the Cambrian of Australia 433
K. P. OAKLEY. An Ordovician Species of *Chaetetes* (Plate XII) 440
R. CASEY. Albian Ammonoid Faunas of Folkestone . . 444
H. I. DREVER. Symplectite-bearing Nodules from Argyllshire 448
H. H. READ. Dalradian Rocks of the Banffshire Coast (Plate XIII) 468
P. E. KENT. Hydraulic Limestones of the Lower Lias . . 476

CORRESPONDENCE.—R. M. Brydone, 479; S. J. Shand, 479.

No. 869. NOVEMBER.

ALAN WOOD. Fish Remains from the North Wales Coalfield 481
J. A. MOY-THOMAS. Structure and Affinities of *Helodus simplex* (Plates XIV and XV) 488
D. CARROLL. Soils of Western Australia 503
J. A. BUTTERFIELD. Outgrowths on Zircon. 511
D. HILL and A. J. BUTLER. *Cymatelasma*, a new Silurian Coral (Plate XVI) 516

REVIEW.—British Regional Geology, 528.

No. 870. DECEMBER.

PAGE

S. R. NOCKOLDS. The Idea of Contrasted Differentiation . 529
J. G. C. ANDERSON. Age of the Girvan-Ballantrae Serpentine 535
A. LAMONT. A Reinterpretation of the Bray Series (Plate XVII) 546
J. P. T. BURCHELL. A Final Note on the Ebbsfleet Channel Series 550

REVIEWS.—Rutley's Mineralogy, 555; Great Earthquakes, 556; The Earth's Magnetism, 558.
REPORTS AND PROCEEDINGS.—Mineralogical Society, 559.
CORRESPONDENCE.—D. L. Reynolds, 562.

INDEX.—563.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIII.

No. I.—JANUARY, 1936.

ORIGINAL ARTICLES.

River Profiles and Denudation-Chronology in Southern England.

By S. W. Wooldridge and J. F. Kirkaldy,
King's College, London.

THE purpose of this paper is to present briefly some conclusions drawn from a study of the longitudinal profiles of rivers in the south of England. In the view of the authors, the study of such profiles affords an important though neglected method of attack on the vexed problems of Pleistocene chronology, and it bids fair also to throw light on certain larger geophysical topics, and particularly on the theory of eustatic movements of sea-level.

At the outset, it is essential that we should explain the body of ideas which form the basis and background of the work, for these are far from being universally recognized in Britain, and require all possible attention and criticism.

It is true to say that the concept of the cycle of erosion as developed by American and Continental workers has made comparatively little appeal in Britain. Geologists commonly dismiss it and all cognate topics as "geography", but even in teaching physical geography they often completely ignore it. The beautifully developed landscapes of Britain seem to have enforced only one truth—it is really a half-truth—on geological consciousness, viz. that "hard" or resistant rock elements tend to stand out in the process of landscape etching, while softer elements are reduced. Most of the British nineteenth century literature on scenery consists of general or particular variations on this theme. Moreover, the same idea found expression in the writings on river-erosion; breaks in the longitudinal profiles of rivers were often attributed simply to the influence of "hard bands". This simple explanation misses the greater and more significant part of the truth, and is based on an erroneous conception of the real character of river-erosion.

A young river beginning its work on an initial or constructional surface will commonly show " consequent " irregularities of profile, but these under normal circumstances will generally disappear by a combination of wearing down and filling up. Later, during the still youthful stages of incision, new inequalities will develop in response to lithological variations within the valley and its terrain. These are incidental to the active stage of " valley-deepening " when down-cutting is at a maximum. They will disappear almost completely by the time a graded condition is reached. The period of survival of any given irregularity depends in part on the resistance of the rock involved ; some few " valley steps " might survive into the graded or mature period, but these too must ultimately disappear, given time. After the graded stage is reached there is, short of considerable uplift and the initiation of an entirely new cycle, only one method by which breaks of profile can be produced ; viz. by small changes of base-level, initiating " waves " of back-cutting or headward erosion, which travel slowly upstream from the mouth. That phenomena of this kind have occurred is sufficiently attested by such cases as that of the American Fall-line, in which a later phase of headward erosion has worked back through the coastal plain sediments to the edge of the older and harder rock masses of the Appalachians. This is what we might term the " Niagara phenomenon " in its normal or general manifestation. It is not only large and spectacular falls which recede upstream and leave behind gorges or valleys within a larger valley. Such action is the normal method of valley-deepening after active downward corrasion has ceased. It depends for its action upon the occurrence of a succession of small negative changes of base-level, each initiating a sub-cycle of back-cutting. Each movement places the stream out of adjustment at its mouth, and the course is then progressively regraded with respect to the new base-level. It should be noted that if the whole of a stream course were tilted by differential movements, it would become simultaneously out of adjustment at all points on its course, and renewed down-cutting would begin throughout. The case here envisaged is different ; it implies a change of base-level uniform in amount over a fairly large region. Either true epeirogenetic or eustatic movements would supply the necessary stimulus, and we need not for the moment pause to argue the claims for recognition of these two types of movement.

The conditions postulated above were realized in Southern England, and indeed over a much wider area, during Pleistocene times. A succession of changes of base-level occurred and, as a result, the longitudinal profiles of the rivers are composite or cyclic, consisting of a number of distinct reaches, each a portion of a curve graded to the present or a former sea-level. The breaks in the curve represent the points reached by the several " waves " of back-cutting ; they may be termed " heads of rejuvenation ", or more concisely, following Knopf, "knickpoints" (14).[1] In the light of the preceding discussion it will be noted that such knickpoints cannot in any case be explained away by invoking resistant rock-bands. If such bands occur, they will tend to retard the upstream recession of the rejuvenation head; in an extreme case, perhaps, one knickpoint might be overtaken by its successor at the crossing point of a hard band. Granted markedly contrasted rock-types in a region, it would probably be true that a majority of the knickpoints would be found located on or near resistant elements, but this will only mean that, as a whole, the knickpoints are at lower points on the river courses than they would have reached in a softer, more homogeneous, rock medium. But in the English plain, and over much of north-west Europe, there are few rocks sufficiently resistant to retard a receding knickpoint for any length of time; only rocks which are essentially chemically resistant, such as quartzites, flinty rhyolites, etc., can cause appreciable distortion of the graphic "uplift record" preserved in longitudinal profiles. In south-east England the *upper portions* of the river curves signify the former attainment of an essentially graded slope. Inequalities of rock resistance expressed during the phase of down-cutting were removed before the attainment of this early, or upper, graded curve. If they have later re-asserted themselves, it is only to emphasize the natural punctuation points in the composite profiles. We may anticipate a further possible objection by pointing out that even in the Palaeozoic tracts of Britain, many "rock-bars" which might be called in evidence against us were produced incidentally to glaciation, not by normal erosion. This is true, for instance, in the Wnion and Mawddach valleys of North Wales with which we are well acquainted. In our one unglaciated upland region, Cornwall and Devon, examination of the stream-profiles quickly shows that variations of rock-hardness provide no explanation of the features. One Greenstone-Killas junction will coincide with a knickpoint while the next is entirely featureless. It is clear that only those geological junctions which coincide in position with normal erosional knickpoints are distinctly marked in the valley bottom. We are not, of course, concerned to deny that in the *stream-bed* as distinct from the valley floor small inequalities of level, often a matter only of inches, reflect differences of rock-constitution. These are quite insignificant in the general view, and outside the limits of the present argument.

Some further general considerations call for comment. It is natural that the rate of recession of rejuvenation heads will be faster in large streams than in small, and we shall hence anticipate some contrast in condition between a trunk stream and its tributaries. Main streams, such as the Thames, possess a sufficient equipment of energy to regrade themselves quickly and completely to successive base-levels. Their tributaries are in very different case. The impulse of back-cutting is handed to them in turn as the main river entrenches itself headwards from the coast. Their regrading processes thus begin at different dates, the downstream tributaries obtaining a start over those which join in the head-water region. Moreover, all the tributaries will normally work more slowly than the main stream, in view of their smaller volume; their steeper slope tends evidently to redress the balance, but the facts show that it does not succeed in doing so completely. Hence it arises that a fuller record of denudation-chronology is preserved in tributary valleys than in those of the main river. In any case, it is to be observed that the preservation of an ideally full record can only result from a nicely balanced tectonic or eustatic "diminuendo" whereby each phase of back-cutting is shorter than its predecessor. Normally, longer continued phases of back-cutting will destroy the handiwork of shorter-lived predecessors, so that only the results of the major changes of base-level, more widely spaced in time, remain legible in the landscape.

---

[1] The numbers in parentheses refer to List of References at end of article.

It will be noted that composite longitudinal profiles, in theory, reveal no more concerning base-level changes than the paired terraces of the valley-side, or the composite transverse profiles of the valley—the "valley-in-valley" conformation—which attests so eloquently the polycyclic character of many landscapes. In practice, there is an important difference, however, for the valley-sides and their terraces are subject to piecemeal destruction by the general atmospheric or valley-widening processes, which do not directly affect the longitudinal profile. Thus the record embodied in them tends to be far less complete, and incidentally far more at the mercy of varying rock resistance. While therefore each knickpoint must correspond with a former terrace or valley-side facet, the latter may be destroyed while the former survives. A complete demonstration of the stages of valley-growth must be based if possible on the correlation of longitudinal and transverse profiles, as employed by Professor Baulig and his school. But in the nature of the case, the longitudinal profile is the more faithful and delicate index of base-level changes, and certainly the first matter to be considered in the physiographic study of a region.

The relation of composite longitudinal profiles to river-terraces involves a most important stratigraphical point, failure to appreciate which has added its share to the confusion of Pleistocene chronology. Clearly, if the profile of a river is composite in the sense here defined, height above the valley bottom is not a criterion of terrace age. Each terrace in its turn merges upstream into the present valley floor at a knickpoint. The rough parallelism between the profile of the present river and those of its terraces, which holds in the case of larger rivers such as the Thames and is rather commonly assumed to be general, is emphatically not true for smaller valleys, e.g. the tributaries of the Thames, and this must be clearly borne in mind in interpreting the archaeological and palaeontological evidence.

In Text-figs. 1 and 2 are reproduced the longitudinal profiles of certain rivers in the Weald, the London Basin, and Wessex. The curve for the Mole has already been published as a result of a co-operative piece of research in which the present authors shared (5). That for the Kentish Stour is based on careful levelling carried out by the authors. For both the Mole and the Stour the method used was to determine with the aid of Abney level and staff the height of a large number of separate points on the inner or riverward edge of the flood-plain, working from the nearest bench-mark or spot-height. This method was only rendered possible by the large number of determined points within reach of these streams. In wilder country, a continuous level traverse would necessarily have to be conducted. In plotting the curves great care was found to be necessary in measuring the distances between points. Inaccurate spacing of the points can clearly lead to the creation of bogus knickpoints. The points were spaced along the median line of the flood-plain, regarded as following the major meanders of the river, but not its minor staggerings. The measurements were actually made with a carefully tested map-measurer, and each one was repeated at least three times and the average taken.

The correspondence between the curves for the Mole and the Stour was so surprisingly close that the great possibilities of the method became immediately clear. The curves for the other rivers were constructed on the same basis, from flood-plain levels and bridge bench-marks taken from the 6-inch maps. It was found that by this method nearly all the knickpoints could be located, or their presence at least suspected. The knickpoint areas were then examined in the field by one of us (J. F. K.), and the evidence confirmed or extended as necessary in the case of the Hampshire rivers.

The visible signs of a knickpoint on the ground vary in distinctness with local variations in the incidence of meander-shifting and lateral erosion below the point of increase of slope. Ideally, one hopes to find at or near the knickpoint the incoming of a low terrace above the river which gradually diverges from the flood-plain lower downstream. This state of affairs is often seen, a particularly good example occurring near Bowley Farm in the headwater region of the Kentish Stour. In many other cases, however, the new or incoming terrace has been cut back or removed completely just below the knickpoint, though it comes in distinctly and at the expected height some little way downstream. The fact that the change of gradient at knickpoints is often too slight to impress the eye in casual scrutiny helps to account for the general failure to recognize the existence of composite profiles in lowland country. It may be noted, however, that many of the old water-mills of southern England were located on or near knickpoints, and many of the riverside towns such as Canterbury, Winchester, and Norwich are sited in significant relation to them.

We may now briefly consider the features of some of the individual curves, and their relations to the terraces.

THE STOUR.

The low-level terrace of the Stour seen east of Canterbury is probably to be correlated with a knickpoint at 32 feet O.D. near the city, but the relations are not entirely clear. At a higher level, a well-marked terrace can be traced from Chislet Forstal to Sturry, where the gravel has yielded Acheulian and Mousterian implements (4). This terrace seems to be double, for beneath the gravels there are two distinct erosion platforms at 60 and 80 feet O.D., respectively. Traced upstream, the terrace gradually approaches the present flood-plain, as is well seen near Shalmsford Street. The two knickpoints which mark the upstream limits of the two parts of the terrace occur in our opinion at Godmersham Bridge (91 feet O.D.), and slightly north of Wye (105 feet O.D.). Above the Sturry terrace at Broomfield, Maypole, and Hoath are other terrace gravels, lying above 100 feet O.D. This terrace passes southwards to Stonerocks Farm, and is recognizable also on the other side of the valley, where, above Fordwich, Mr. Reginald Smith has recently recorded an important occurrence of Clactonian implements in gravels whose base is at 130 feet O.D. (13). The deposits may in part appertain to the Little Stour here, but the same terrace can be traced west of Canterbury in the valley of the Great Stour, near Cockering Farm and elsewhere. It re-appears at Ashford and grades back to a knickpoint at Little Chart at 191 feet O.D. At Bowley Farm, near Lenham, there is a well-marked knickpoint at 283 feet O.D., and deposits associated with a former continuation of the curve above Bowley Farm can be traced at Boughton Aluph, north of Ashford, and at Hurst Farm near Chilham, and they are probably correlative with certain of the high-level gravels round Tylers Hill and Blean Woods, north of Canterbury. It is evident that at this early stage in its history the Stour flowed northwards over the London Clay area of the Blean, and it has since worked steadily eastwards towards its present course as it cut down.[1]

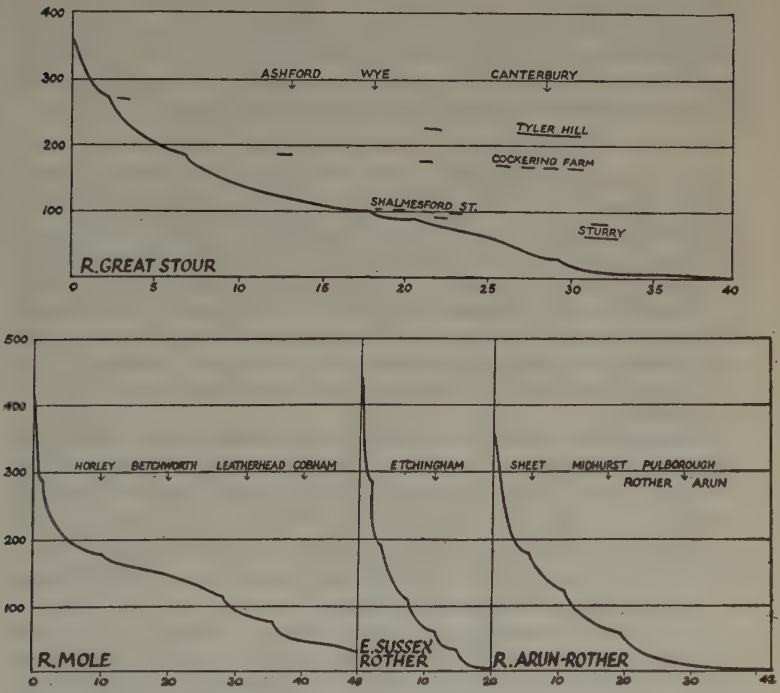
THE MOLE.

A full account of the terraces of the Mole has recently been published (5), and we shall give here only a brief summary of the relevant features. The best marked terrace is that represented by a conspicuous flat in the Mole Gap at Mickleham at about

---

[1] See map by present authors in R. A. Smith (13).

140 feet O.D. This is traceable downstream into the Boyn Hill (" 100 feet ") terrace of the Thames. Upstream it grades to a knickpoint at Meath Green (173 feet O.D.). Near Betchworth and Brockham are higher gravels at about 200 feet O.D., which represent a terrace associated with the highest knickpoint of the Mole at 290 feet O.D. near Broadfield. The lowest of the knickpoints, which occurs at 81 feet O.D. near Downside Mill, Cobham, is the evident associate of a terrace continuous with the Taplow terrace of the Thames. Like the Sturry terrace, it gives some evidence of being in reality a double feature whose upper portion is perhaps related to a knickpoint at Norbury Park (118 feet O.D.).



TEXT-FIG. 1.—Longitudinal Profiles of Rivers in the Wealden area. Terraces indicated at appropriate position and altitude in the case of the River Stour. Distance in miles. Height in 100 ft. intervals.

It will be noted that the correspondence between the main features in the Stour and the Mole is remarkably close. The general form of the curve in each case reveals an interesting feature. The upper part as a whole is broadly concave, but the middle portion round about 100 feet O.D. descends much more steeply, and is broadly convex. This general convexity evidently indicates a rapidly dropping base-level at this stage.

THE ROTHER-ARUN.

The terraces of the Rother-Arun are poorly developed, but appear to be capable of correlation with their knickpoints at 180, 160, and 60 feet O.D., respectively. Gravels corresponding with the highest knickpoint occur at 150 feet O.D. at Fitzlea Farm near Selham, and also at Burton Rough. The extensive gravel spreads above the trench of the Rother near Midhurst represent the next terrace, just below the point where it grades back into the present flood-plain near Chithurst. The gravel just above the flood-plain near Selham (50 feet O.D.) represents a lower terrace grading back into the present valley floor near South Ambersham.

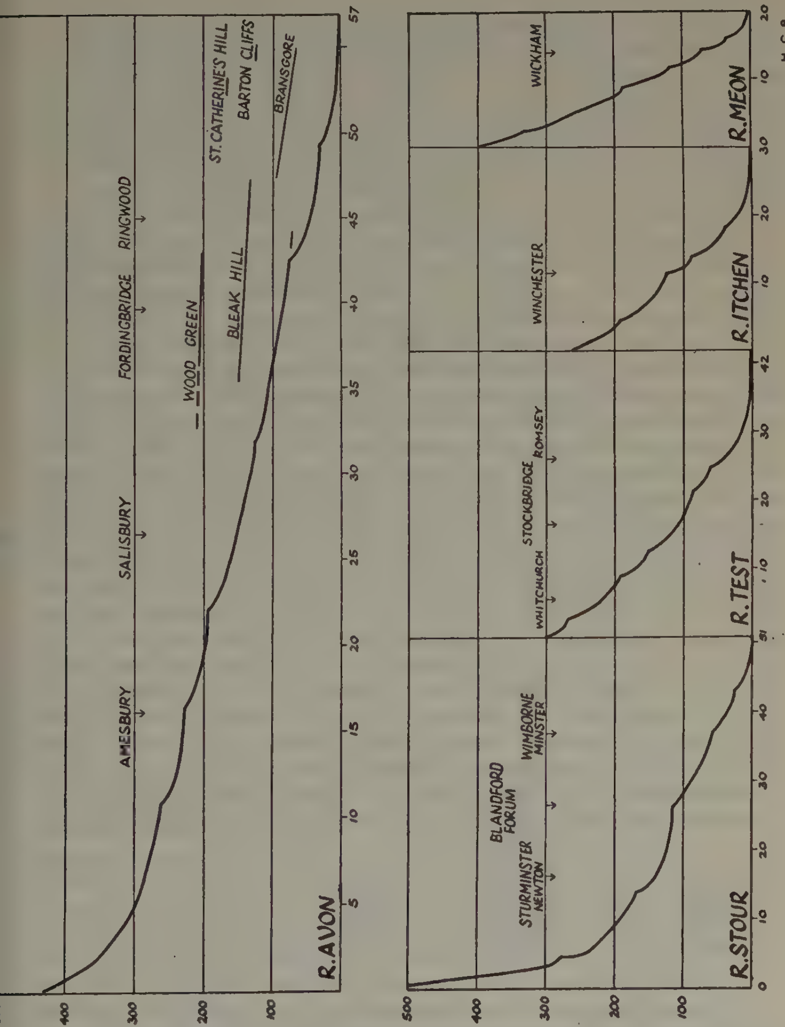
THE RIVERS OF THE HAMPSHIRE BASIN.

The transverse consequent rivers of the Hampshire Basin (Meon, Itchen, Test, Avon, and Stour) were formerly tributaries of the longitudinal "Solent River", and their evolution must be interpreted in the light of this fact. There is a considerable literature on the terrace-gravels of the region, principally the work of C. Reid (11, 12), Osborne White (6, 7, 8, 9), and H. Bury (1, 2). We cannot here embark on a full discussion of this literature; our conclusions are partly at variance with those of former writers, and we put them forward in no dogmatic spirit but as a contribution to discussion.

It should be noted that in addition to the terrace gravels, clearly related to the present streams, there are plateau gravels above 250 feet O.D., and also a composite gravel ledge along the coastline between the Avon and Southampton Water. The latter gravels are to be regarded as the deposits of the Solent River itself, and their several stages can be correlated to some extent with the terraces of the southward flowing tributaries.

We shall first consider the well-developed terraces of the Avon in relation to the longitudinal profile. The lowest, or Bransgore, terrace may be correlated with gravels at 60 feet O.D. at Highcliffe, and grades back to a knickpoint at Downton at 125 feet O.D. At a higher level occurs the so-called Palaeolithic terrace (11, p. 50); it appears probable that it includes representatives of two or more distinct terraces. A lower portion or Bleak Hill terrace can be traced above the right bank of the river for many miles near Ringwood, and is correlated by White with gravels at 120 feet O.D. at Barton Cliffs. It grades back to present flood-plain level at 190 feet O.D. at Heale House. On the opposite bank of the river an upper, or Wood Green, terrace occurs at about 200 feet O.D. It may be represented upstream by small masses of gravel between Salisbury and Amesbury, and it corresponds in our view with a knickpoint at 260 feet O.D. at Figheldean, and with gravels on the higher parts of the coastal ledge at Hinton Admiral.

The implement-bearing gravels at 162 feet O.D. on St. Catherine's Hill cannot readily be correlated with either of the above terraces, and we suggest tentatively that they belong to an intermediate terrace corresponding to a knickpoint at 220 feet O.D. at Amesbury.



TEXT-FIG. 2.—Longitudinal Profiles of the Wessex Rivers. Terraces shown for the River Avon. Distance in miles. Height in 100 ft. intervals.

In the Stour valley, the Lamb's Green terrace (11, p. 55) evidently corresponds with the Bransgore terrace, and similarly grades to a knickpoint at 125 feet O.D., while at a higher level the Higher

Merley terrace grades back into the flood-plain at 162 feet O.D. Above this, Bury recognizes a Sleight terrace corresponding with the gravels at St. Catherine's Hill (2) which would grade into the knickpoint at 210 feet O.D. Higher spreads of gravel above 200 feet O.D. near Canford may correspond with the knickpoint at 275 feet O.D.

In the Test valley near Timsbury are two well-marked terrace stages, the Mottisfont stage at 100–120 feet O.D., and the Belbin's stage at 120–150 feet O.D. (6). In our view, they correspond respectively to knickpoints at 147 feet O.D. at Wherwell and 190 feet O.D. at East Acton. Between Horsebridge and Marshcourt Farm there appear to be remains of a higher terrace corresponding with the clearly marked knickpoint at Southington.

The terraces of the Itchen are poorly developed. White, employing the criterion of height above the present valley floor, correlates the Twyford spread at 123 feet O.D. with the Mottisfont stage of the Test (6, p. 73), but viewed in relation to the longitudinal profile it seems more probable that it corresponds with the Belbin's stage, and the knickpoint at 190 feet O.D. On this view, the equivalents of the Mottisfont stage are not clearly developed, unless they are represented by gravel spreads at about 60 feet O.D. near Swaythling.

The Meon is the smallest and steepest of the group of Hampshire rivers, and it flows only for a short distance over the soft Eocene rocks which favour terrace formation. It is therefore not surprising to find but a scanty terrace record. However, we can correlate the gravel spread capping the bluff at Great Posbrook with the knickpoint at 185 feet O.D., while the gravels below the bluff, and the low terrace gravels at Mislingford, Wickham, and Tapnage apparently correspond with the knickpoint at 120 feet O.D. The low level terrace at Titchfield grades back to the present flood-plain at 30 feet O.D. near Great Fontley Farm. A higher terrace may be represented by gravels at about 150 feet O.D., south-east of Cliphall, and by gravels at a slightly lower level near Wickham, but there is no sign of any corresponding knickpoint.

As a result of a study of the curves for the Hampshire rivers, we venture to suggest the following correlation of the several terraces.

Stour.	*Avon.*	*Test.*	*Meon.*
	Wood Green		
Sleight	St. Catherine's ?		
Higher Marley	Bleak Hill	Belbin's	Upper Posbrook
Lamb's Green	Bransgore	Mottisfont	Lower Posbrook

This correlation is based entirely on morphological evidence, considered always in relation to the form of the longitudinal profiles. If archaeological evidence should ultimately indicate a different correlation, some no doubt will prefer to say, "So much the worse for the supposed morphological evidence." But this consideration is evidently double-edged, and for our own part we do not regard the chronology of culture stages as established with such certainty and detail as to enable it to override a large body of explicit physical evidence. In any case, application of two independent methods is likely to lead us nearer to the truth than the exclusive use of one. So far as we have been able to ascertain, the above correlation is broadly consonant with the archaeological evidence gathered from the terrace gravels, and it also falls into line with the sequence of raised beaches established by Palmer and Cook (10) in the Portsmouth district. Our interpretation, however, diverges somewhat from the latest views of Mr. Bury on the gravels of the Bournemouth district (2). He invokes phases of aggradation so extensive that the deposits of a later stage may extend up to and even over those of an earlier stage. This is an idea we find it rather difficult to accept, but in view of Mr. Bury's long researches in the area it would be an impertinence to dismiss it without full consideration. If he is right, some of our conclusions are invalidated, or at least complicated.

CONCLUSIONS.

This investigation, the main results of which are summarized in Text-figs. 1 and 2 and Tables A and B, was undertaken in a spirit of pure curiosity, and not to support or negative any particular theory. The results, with certain significant exceptions, are so alarmingly consistent as to convey the impression of proving too much. They have indeed occasioned a great deal of mental questioning on our part during the last two years. Nevertheless the figures have been carefully arrived at, and if accepted at their face value point to conclusions both important and far-reaching. We are satisfied that these conclusions are neither improbable in themselves, nor inconsistent with our other knowledge of the areas concerned, and we therefore venture briefly to indicate them.

It will be seen from Tables A and B that the several groups of knickpoints maintain singularly constant levels throughout the region (excluding East Anglia), and are spaced at comparable proportionate distances along the streams. This indicates incidentally that there has been no marked lag in the headward propagation of phases of rejuvenation as between one part of the region and another. This fact reflects the relative closeness to the sea, or to the trunk streams of all the points in question, and the general lithological homogeneity of the whole region. The discussion in the earlier part of the paper will have made it clear that there is no necessary reason why phases of rejuvenation should work back to knickpoints at the same height; this clearly involves the distance to be traversed and the quality of the rocks to be excavated. Yet, for our region, the close correspondence of knickpoint levels is striking, and this at least removes one difficulty which otherwise might tend to obscure the fact that the greater part of the region was sculptured under the influence of *successive uniform changes*

TABLE A.

Showing heights of knickpoints (rejuvenation heads) in the Rivers of the Weald and the Hampshire Basin. The heights are given in feet above O.D.; the figures in parentheses show the proportionate distances, measured upstream, of the knickpoints.

THE WEALD				HAMPSHIRE BASIN					
Mole	Gt. Stour	Rother (E. Sussex)	Rother-Arun	Meon	Itchen	Test	Avon	Stour	
290 (·97)	283 (·96)	290 (·94)	—	—	—	260 (·93)	260 (·80)	275 (·90)	
—	—	—	—	—	—	—	220 (·69)	210 (·83)	
173 (·77)	191 (·83)	195 (·88)	180 (·88)	185 (·55)	190 (·85)	190 (·81)	190 (·61)	162 (·71)	
118 (·43)	105 (·59)	114 (·74)	120 (·74)	120 (·40)	120 (·62)	147 (·67)	125 (·43)	125 (·52)	
81 (·30)	91 (·51)	70 (·59)	—	70 (·27)	88 (·53)	88 (·46)	—	—	
—	—	—	60 (·52)	—	—	60 (·39)	60 (·25)	60 (·27)	
—	32 (·31)	30 (·46)	—	30 (·13)	40 (·40)	—	30 (·16)	28 (·12)	
49	39	20	41	20	30	42	57	51	Length of River in miles.

TABLE B.

Showing heights of knickpoints (rejuvenation heads) in the East Anglian and certain other rivers. Heights given in feet above O.D.

TRIBS. OF THAMES			EAST ANGLIA					
Exe	Colne	Lea	Chelmer	Pant	Colne	Stour	Brett	Gipping-Orwell
750	—	—	—	—	—	—	—	—
575	—	—	—	—	—	—	—	—
350	—	342	—	—	—	—	—	—
318	—	—	—	—	—	—	—	—
288	—	—	—	218	230	240	230	—
235	220	235	—	160	—	177	188	—
180	174	176	—	130	140	145	—	—
136	116	119	105	90	105	105	112	90
70	—	91	55	55	68	65	73	73
32	—	—	—	—	40	—	22	—

of base-level. Each group of knickpoints represents a former sea-level. By applying suitable mathematical formulae to the curves, and, for the older stages, reconstructing as nearly as possible the position of former shore-lines, we might attempt to calculate these actual sea-levels. We have, however, satisfied ourselves in consultation with mathematical colleagues that the form of expression successfully used by O. T. Jones and J. F. N. Green for extrapolation on river curves is not the only one which might be deemed to fit the case. This branch of the subject is at present too empirical in its method to command universal assent. Moreover, in the case of the figures before us the approximate positions of the operative marine base levels are clearly apparent from the form of the curves, or the height of the terraces on the coastward tracts, and it is doubtful if much could be added to the picture thus presented with the help of calculations based on curve-forms. In short, where reasonably numerous relics of the corresponding terraces exist below a knickpoint, the form of the curve is *known* and need not be computed.

In the light of the facts set forth above the outstanding characteristic of our region during the later stages of its growth has been an absence of differential warping. We may, perhaps, be permitted to state that in our view this implies eustatic changes of sea-level. We do not believe that epeirogenetic uplift of so uniform a character is normally within the range of physical possibility. If it is, then it must be admitted that epeirogenetic movements of the land will explain the facts quite as well as eustatic movements of sea-level. It is, however, with effects rather than causes that we are dealing here, and the major effect has certainly been an absence of differential warping over the greater part of the area. The Weald and the Hampshire region give absolutely consistent results, and the data quoted for the Exe in Table B extend the area so characterized far to the west. In the area north of the Thames different conditions hold ; the area was ice-loaded and remains in great part drift-covered. Nevertheless, the Colne and the Lea have curves comparable with those of the southern rivers, and it is only in Essex and East Anglia that marked differences come in. Here the curves and the height and spacing of the knickpoints are different. It may be remarked that over the greater part of the area the river curves merely confirm the indications of higher unwarped platforms or hill-top-planes. Whether in Hampshire, the Weald, or the London Basin, it is possible to identify such bevelled upland surfaces, or areas of accordant summit level which have been " uplifted " without warping, or at any rate with quite inconsiderable warping. If these older surfaces are so disposed, the much younger river terraces must *ipso facto* be undistorted. Some authors, however, have invoked considerable folding or warping movements in Pleistocene times within the area. In our view, the " folds " to which they refer have no real existence. But if we grant for the sake of argument that such movements took place, affecting the higher levels, then the evidence of the river profiles gives an upper limit of date for such movements, for whatever doubts may attach to "platform" hypotheses the evidence we now present appears to lead to inescapable conclusions. The discrepancies between the East Anglian region and the rest of the area considered strengthen the general conclusions rather than the reverse, for they could have been anticipated. Apart altogether from the problematical isostatic effects of ice-loading, the East Anglian region has tectonic relationships which differ entirely from those of the London Basin and the regions to the south. It has functioned as a portion of the subsiding margin of the North Sea depression. The sub-drift surface descends from a very constant level at about 200 feet O.D. in Central Essex to considerable depths below sea-level beneath Suffolk and Norfolk. A similar downwarping towards the east, or north-east—a recrudescence indeed of the well-known Pliocene movement *en bascule*—may well have occurred in late Pleistocene times. Such indeed is the indication of the river-curves and of the occurrence of Clactonian implements at unusually low elevations.

One further conclusion of a physiographic nature emerges from this study. Crickmay (3) has recently thrown doubt on some of the basic ideas of the cycle of erosion and peneplanation, stressing the efficacy of lateral corrasion by rivers leading to the production of "panplanes". In our opinion, his view is too strongly coloured by the conditions found in continental interiors of sub-humid or semi-arid climate. For such regions his thesis holds out a valuable addition to the theory of the cycle of erosion. On the other hand, quickly successive phases of rejuvenation working back from the coast put very definite limits to lateral corrasion in the regions of the continental margins. There is never a sufficient interval for lateral corrasion to supervene in force. While, moreover, the processes we have described lengthen the period of valley deepening, they in no way impede the normal sub-aerial wastage of divides which must lead ultimately to a peneplain. The successive changes of base-level are none of them large enough to initiate a new major cycle. They punctuate a major cycle with sub-cycles, and while each contributes in its turn to the fashioning of the valley floors, the evolution of the landscape as a whole, including *inter alia* the gradual wasting of interfluves, proceeds normally with respect to the general or average base-level. It is only in regions far from the sea that lateral corrasion can effectually rival interfluve wastage in the production of base-levelled tracts.

In conclusion, we should like to express our cordial thanks to Professor Baulig of the University of Strasbourg for most helpful discussions. This work was complete before he lectured in 1933 in the University of London,[1] and its main conclusions had indeed been communicated to Section C of the British Association for the Advancement of Science. It was, however, only in conversation with Professor Baulig that we realized that conclusions which might conceivably evoke surprise or doubt in the minds of our British colleagues were commonplace to him and to his students. We found that ideas had grown independently on very similar lines in two corners of the European " Babel ", and an interchange of views proved most stimulating.

---

[1] These lectures have since been published under the title of *The Changing Sea Level*, Institute of British Geographers, Pub. No. 3, 1935.

References.

(1) Bury, H., 1923. " Some Aspects of the Hampshire Plateau Gravels," *Proc. Prehist. Soc. E. Anglia*, iv, 15.

(2) —— 1933. " The Plateau Gravels of the Bournemouth Area," *Proc. Geol. Assoc.*, xliv, 314.

(3) Crickmay, C. M., 1933. " The Later Stages of the Cycle of Erosion," Geol. Mag., LXX, 337.

(4) Dewey, H., 1925. " The Palaeolithic Gravels of Sturry," *Proc. Geol. Assoc.*, xxxvi, 278.

(5) Green, J. F. N., and others, 1934. " The River Mole ; its Physiography and Superficial Deposits," *Proc. Geol. Assoc.*, xlv, 35.

(6) Osborne White, H. J., 1912. " The Geology of the Country around Winchester and Stockbridge," *Mem. Geol. Surv.*

(7) —— 1913. " The Geology of the country near Farnham and Havant," *Mem. Geol. Surv.*

(8) —— 1915. " The Geology of the country near Lymington and Portsmouth," *Mem. Geol. Surv.*

(9) —— 1917. " The Geology of the country around Bournemouth," *Mem. Geol. Surv.*

(10) Palmer, L. S., and Cook, J. H., 1923. " The Pleistocene Deposits of the Portsmouth District and their Relation to Man," *Proc. Geol. Assoc.*, xxxiv, 253.

(11) Reid, C., 1902. " The Geology of the country around Ringwood," *Mem. Geol. Surv.*

(12) —— 1902. " The Geology of the country around Southampton," *Mem. Geol. Surv.*

(13) Smith, R. A., 1933. " Implements from High-Level Gravel near Canterbury," *Proc. Prehist. Soc. E. Anglia*, vii, 165.

(14) Knopf, E. B., 1924. " Correlation of Residual Erosion Surfaces in the Eastern Appalachian Highlands," *Bull. Geol. Soc. Amer.*, xxxv, 636.

Leucite-Basanite in East Lothian.

By D. Balsillie, Royal Scottish Museum, Edinburgh.

ONE mile due east of Tantallon Castle, on the East Lothian coast, there stands a conspicuous tower or beacon. Its purpose is to afford an offshore warning to mariners. It has been constructed upon the seaward extremity of a northerly-extending ridge of volcanic ash or agglomerate. In recent years the rocks exposed here have been carefully examined by a well-known Edinburgh geologist, the late Mr. T. Cuthbert Day, and his results are reported in an interesting paper entitled " Volcanic Vents on the Coast, from Tantallon Castle eastwards to Peffer Sands, and at Whitberry Point " (*Trans. Edin. Geol. Soc.*, xii, 1930, p. 213). Mr. Day thought that the ash and agglomerate lying south of the beacon represented the materials belonging to two contiguous but distinct volcanic vents of Lower Carboniferous age. To the twin orifices he applied the designation—"The Car Double Vent." In the northerly vent there occur two basaltic intrusions intersecting the pyroclastic rock. One of these, an irregular 4 ft. dyke, trends north-west hard by the easterly side of the beacon. The other, an oval plug covering 500 square feet, or thereby, is situated about 100 yards to the south-east. Both masses were determined petrographically by Mr. Day as " dark red basalt with conspicuous dark crystals of augite, somewhat decomposed, but appearing under the microscope to approach a limburgitic type ". It is in reference to these " limburgitic " intrusions that I present the following brief note, because, lately, I have discovered that they consist of leucite-basanite, a rock of basic felspathoidal character not previously known to occur in this country. The information given below, it is necessary to explain, is based mainly upon an examination of material collected from the plug-exposure, about 100 yards to the south-east of the beacon.

In the freshest obtainable hand-specimens the body of the rock is compact, of a dark-brown to brown-black colour, and it possesses in places a sub-resinous lustre. It carries innumerable microphenocrysts (< 2 mm.) of unaltered augite, much less abundant limonite, serpentine, and iddingsite pseudomorphs after microporphyritic olivine, and rare lustrous 0·5 cm. phenocrysts of brown-black hornblende. The rock is veined and stained with red iron oxide and it is traversed by joints and fissures, upon the faces of which there are usually hematitic and limonitic coatings.

Upon examination under the microscope it can be seen that the ground of the " limburgite " is not uniformly compounded. Some parts of the mass prove to be highly glassy, whilst others show a holocrystalline development of the constituents. The porphyritic minerals, however, do not appear to vary in their distribution. Augite is found not only as phenocrysts but also as an essential component of the ground. The phenocrysts tend to equidimensional idiomorphism, although very many of the smaller crystals are sub-angular or rounded in outline. On a fractured surface of the rock 1 square inch in extent there may outcrop as many as 200 1 mm. augite phenocrysts. By transmitted light their colour is ordinarily a faint uniform purple. But occasionally they show more distinctly tinted borders and exhibit chrome-diopside or aegirine-augite cores which, especially in sections parallel to the optic normal, display a curious violet to green pleochroism. The axial angle of the pyroxene $2V = 54°–56°$, and the extinction $Z.c = 46°$. The crystals are often embayed by the base and they carry inclusions of granules and plates of iron ore, or obscure glassy material. Not rarely their substance is observed to be traversed by curious ramifying bulbous tubules, that seem either to be empty or to contain a little cryptocrystalline ground. Usually the phenocrysts are zoned but only seldom do they show a typical hour-glass structure. Sometimes they yield patchy extinctions, due probably to a slight variation in composition, or to an imperfect parallelism, of the successive zones of accretion. Nearly all of them show a marked inclined dispersion.

The other porphyritic constituents of the rock are olivine and hornblende. The former occurs as 1 mm. limonitic, serpentinous and iddingsitic pseudomorphs, these (together) numbering about fifty for each square inch of rock examined. The hornblende megaphenocrysts are relatively rare, although two or three can generally be detected in each thin section. It seems reasonable to suppose, from their rounded and corroded outlines, that much of their substance has been resorbed. Almost invariably the crystals are surrounded by a dark zone of granular iron ore, or iron ore and augite. Intergrowth or association with purple or green augite is not infrequently observed. The amphibole has an extinction $Z.c = 22°$ and determinations of the axial angle 2V over the bisectrix X afforded values ranging from 78°–82°. The pleochroism is X pale-yellow, Y yellow-brown, and Z sienna-brown. These optical properties do not seem to indicate that the mineral is barkevikite; rather do they suggest that it corresponds with the brown hornblende known to occur in the kulaite of Blaikie Heugh (ref. "The Geology of East Lothian," *Mem. Geol. Surv.*, 1910), in the phonolite of Traprain Law, and in some of the trachybasalts and trachyandesites of North Ayrshire (ref. "The Geology of North Ayrshire," *Mem. Geol Surv.*, 1930).

The ground of the rock immediately calls to mind some of the continental leucite-bearing basanites and basalts. It is of a grain size 0·1–0·2 mm. and it consists of labradorite, augite, magnetite, analcite, leucite, and glass. The laths of soda-lime felspar have been extensively replaced by analcite, which mineral seems to form a large part of the substance in which the other constituents lie. Resulting from this substitution certain portions of the mass appear now to be devoid of determinable felspathic content. Augite occurs as minute, colourless or pale purple, idiomorphic prisms and granules. Magnetite, more or less oxidized, in the form of dust or as little squares and angular plates, is an important ingredient and the one to which must be attributed the staining and discolouration of the rock. Leucite is readily recognizable in 0·1 mm. isotropic, octagonal, sections crowded with inclusions, the study of which with a good high power dry or immersion lens is very interesting. The inclusions consist mainly of diminutive acicular crystals of monoclinic pyroxene and rods and granules of magnetite. Sometimes the pyroxene needles are arranged parallel to the polygonal boundaries of the felspathoid, and often it can be noticed that they occur segregated into concentric zones, the centres of the crystals and interzonal areas remaining quite translucent. Or, again, the leucite may be found constructed around a little nuclear idiomorph of augite, or clump of irregular granules of augite and comminuted magnetite. Many of the crystal edges have been rounded and the mineral has been very largely replaced by analcite. Only, indeed, from fusibility tests in a Meker burner has it been inferred that there is any of the original leucite remaining. Dark russet, obscure, dusty glass is observable in many sections, and occasionally the rock is micro-fluxioned into bands that differ in the proportion of vitreous matter present.

The narrow dyke at the beacon is porphyritic in respect of augite, olivine, and hornblende. It is of a red-grey colour in the central part and hematite-red along the compact chilled margins. Microscopically it proves to be a glassy vesicular rock. The glass is heavily charged with red-brown or black iron-oxide and crowded with laths of soda-lime felspar and minute crystals and fragments of augite. Analcitic pseudomorphs after leucite irregularly strew the ground. These are surrounded by shells of rust-coloured glass and they often reveal a radiate disposition of enclosed opaque fibrils of iron ore. The vesicles are filled with chlorite, analcite and calcite.

It ought to be mentioned that twenty-five years ago Professor E. B. Bailey suspected the former presence of leucite in the kulaite of Blaikie Heugh (op. cit., 1910). The rocks above noted, carrying abundant ferromagnesian in the ground, are probably of slightly more basic composition. Their affinity, however, mineralogically with the hornblende-bearing basalts and trachybasalts is evident. Thus it appears not unlikely that leucite will yet be reported from other localities in Central Scotland.

In conclusion a word of warning may advisedly be conveyed to any geologist who should have it in mind to collect the Car Vent intrusions. They are accessible only at low water and difficult seas often run along the East Lothian coast. Any excursion, therefore, that it is proposed to make should be arranged with careful reference to the local tide-table.

Rhaphidograptus, a new Graptolite Genus.

By O. M. B. Bulman, Sedgwick Museum, Cambridge.

Introduction.

The genus *Dimorphograptus* was founded by Lapworth (1876) for uni-biserial graptolites transitional between *Diplograptus* and *Monograptus*, evolution along what is now termed the "Monograptid trend" leading to the production of a uniserial proximal portion of the rhabdosome. *Akidograptus* has been proposed more recently by K. A. Davies for an early stage in the *Dimorphograptus* series, represented by the species *Ak. acuminatus* (Nicholson) and *Ak. ascensus* Davies.

Dimorphograptus is a polyphyletic genus, in which the thecae may, in various species, be of *Orthograptus*, *Glyptograptus*, or *Amplexograptus* type (Elles and Wood, 1908, p. 348), but it is essentially an intermediate between *Diplograptus* (*sensu lato*) and *Monograptus*. Wiman had long ago suggested (1895, p. 32) that *Monograptus* might arise both from Diplograptid and Climacograptid ancestors, but he gave no details, and no Climacograptid showing corresponding proximal-end changes to those known in the Diplograptid series has till now been recognized.

It is here proposed to separate under the new generic name of *Rhaphidograptus* (genotype: *Climacograptus törnquisti* Elles & Wood), a form which owes its distinctive characters to an operation of this Monograptid trend on a Climacograptid stock.

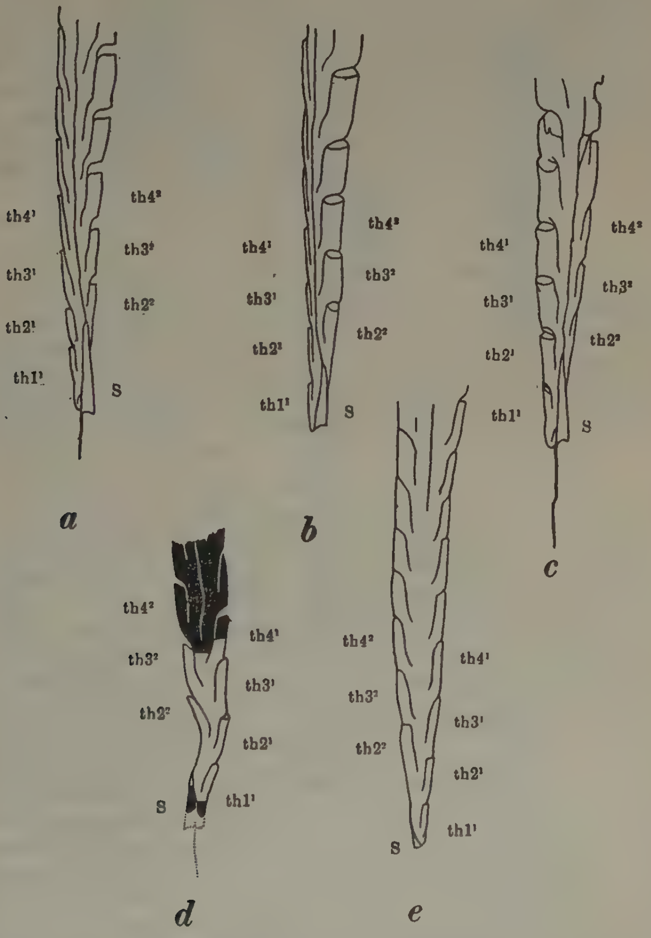
STRUCTURE OF THE PROXIMAL END IN *CLIMACOGRAPTUS TÖRNQUISTI* ELLES & WOOD.

The species *törnquisti* was founded on a Climacograptid of *scalaris* type, in which the proximal end has "an appearance closely resembling that of a *Dimorphograptus*", with the sicula free for nearly the whole of its apparent length on one side. Elles and Wood further state (1906, p. 190) that "th1^2 is so unusually long that its aperture is above the level of that of th2^1", and again (*ibid.*, p. 191): "*Climacograptus törnquisti* is clearly closely related to the *Dimorphograpti*, but since th1^2 seems to develop as usual from th1^1 and the Dimorphograptid appearance is merely due to its peculiar [upward] direction of growth and unusual length, the species must be regarded as a *Climacograptus*." Törnquist, writing of the species under the name *Cl. rectangularis* McCoy, is rather less explicit, but says (1897, p. 8): "Owing to the circumstance that the first thecal orifice of the secondary series is situated beyond the second aperture in the opposite row, the dorsal wall of the sicula is free for more than half its entire apparent extent, and the sicula itself is visible, even in the reverse aspect, in the form of an elongated triangle." (See Törnquist, 1897, pl. i, fig. 19; or text-figs. 1 *d* and *e* of this paper.)

Examination of pyritized specimens of this species preserved in full relief leads me to suggest that the "first thecal orifice of the secondary series", th1^2 of Elles and Wood, is in reality th2^2, and that the distal part of th1^2 does not develop in this species.[1] It will be seen from text-figs. 1 and 2 that in this species, as in *Akidograptus acuminatus* (text-fig. 2 *b*), either th2^2 and th3^1 are produced from th2^1 in the normal manner, in which case th1^2 must be lost (as shown in text-fig. 2); or else two buds (th2^1 and th2^2) must have been produced from th1^2, which is a structure that cannot be derived from any known Diplograptid (cf. Elles, 1922, p. 173, and Bulman, 1932, p. 10). The interpretation advocated is shown by the lettering of the accompanying text-figs. 1 and 2 *a*. The loss of

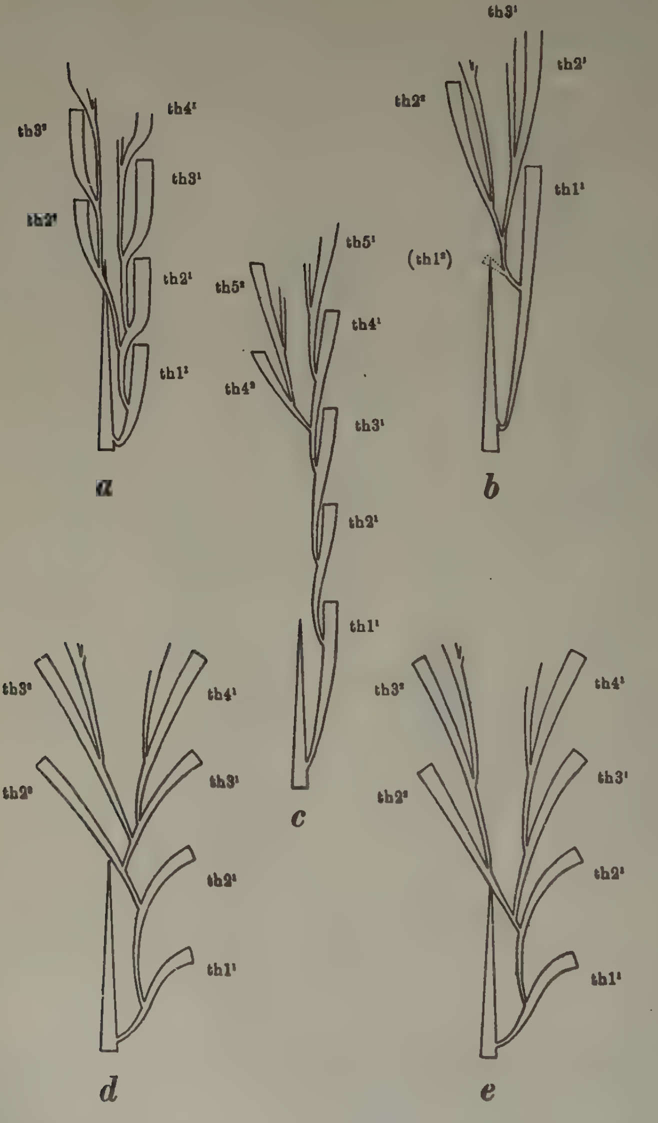
---

[1] The writer has elsewhere (1932, p. 24) expressed the view that the proximal part of all thecae should perhaps be regarded as a coenosarc or "common canal", and on such a view the proximal part of th1^2 would still be present, connecting th1^1 and th2^1.



TEXT-FIG. 1.—*Climacograptus törnquisti* Elles & Wood, Lower Llandovery Series. *a, b, c*, obverse aspect; *d, e*, reverse aspect. × 8 approx.

a. *M. acinaces* zone, Rheidol Gorge, near Pont Erwyd, Cardiganshire. Sedg. Mus., No. A 7694.
b. *M. cyphus* zone, Great Rundale Beck, Westmorland, Sedg. Mus., No. A 7701.
c. *M. cyphus* zone, Rheidol Gorge. Sedg. Mus., No. A 7695.
d. *M. cyphus* zone, Great Rundale Beck. Sedg. Mus., No. A 7697.
e. *M. triangulatus* zone, Rheidol Gorge. Sedg. Mus., No. A 7696.

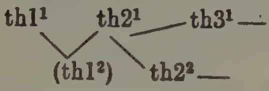


TEXT-FIG. 2.—Thecal diagrams to illustrate the structure of the proximal end in: *a*, *Climacograptus törnquisti*; *b*, *Akidograptus*; *c*, typical *Dimorphograptus*; *d* and *e*, possible alternative interpretations of *Dimorphograptus decussatus*. (For drawings of the actual proximal ends corresponding to figs. *b* and *c*, see *Arkiv för Zool.*, 1932, 24A, No. 13, pl. 3.)

th1^2 in *Climacograptus törnquisti* implies a change which is quite analogous to the loss of this theca in *Akidograptus* and to that represented in or leading to *Dimorphograptus*.

THE STRUCTURE OF *AKIDOGRAPTUS* AND *DIMORPHOGRAPTUS*.

Akidograptus was defined by Davies (1929, p. 9) as being a transient form between *Diplograptus* and *Dimorphograptus*, but with no definite uniserial portion. In a previous paper (1932, p. 16) the present writer suggested that the distal part of the first theca of the second series was lost within the generic concept of *Akidograptus*, so that the thecal formula might be written :—



(text-fig. 2*b*)

but that owing to the shortening of th2^2 and that part of the "common canal" involved, it happens that th2^2 opens below the level of th2^1 and there is no obvious uniserial stipe. A very much shortened and vestigial th1^2 seems to be present in the genotype, *Ak. ascensus* Davies. The essential features of the *Akidograptus* development may therefore be summarized :—

(1) marked reduction or loss of the distal part of th1^2,

(2) retention of the downward direction of growth of the initial part of th1^1 as in normal *Diplograpti*,

(3) shortened condition of th2^2 and early development of th2^1, th2^2, etc., masking the loss of th1^2.

The typical Dimorphograptid (text-fig. 2 *c*) differs conspicuously in the more elongate uniserial part of the rhabdosome, resulting from a further loss of thecae on the side of the secondary series. The first theca present on that side seems usually to be much shorter than a normal theca of the species (thus, in text-fig. 2 *c*, th4^2 is short and opens below the level of th4^1).

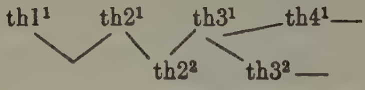
The length of the uniserial portion of the rhabdosome is variable, though apparently very constant in a given species, and it is perhaps remarkable that we find so few *Dimorphograpti* with very long uniserial portions ; that is, so few that might be said to be nearer *Monograptus* than *Diplograptus*. A possible explanation of this is that the progressive loss of thecae of the second series can only occur up to that point at which the rhabdosome becomes separated into two uniserial stipes by a median septum.[1] Once two linear series of thecae have been produced by the formation of two buds from a preceding theca, loss of the initial theca of the secondary series would result in the loss of the whole stipe based upon it (e.g.

---

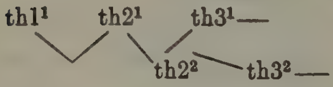
[1] In this connection a partial septum appears to act as effectively as a complete one.

th4^2 in text-fig. 2*c*). That is to say the loss of the single theca underlying the median septum would convert the rhabdosome mutationally (saltationally) into a Monograptid. In the ancestral Diplograptids upon which the Monograptid trend (loss of secondary series of thecae) operated to give *Dimorphograptus*, the non-septate trend (leading to the production of an alternating series of thecae by progressive delay in the formation of two linear series) had not perhaps advanced very far; hence the majority of Dimorphograptid species would only possess a short uniserial portion.

Certain Dimorphograptids, however, such as *D. physophora* (Nicholson) and *D. decussatus* Elles & Wood, have an extremely short uniserial portion, apparently consisting of one theca only, and in this respect resemble *Climacograptus törnquisti* or *Akidograptus*. My interpretations of the structure of *D. decussatus* are shown in text-fig. 2 *d* and *e*; preservation of the available material is not sufficiently good to allow of a definite decision between these alternatives, viz. :—



(text-fig. 2*d*)



(text-fig. 2*e*)

but the former seems rather more probable, since it would admit of the loss of a further theca in the secondary series, th2^2, as occurs in *D. decussatus* var. *partiliter* Elles & Wood.

Whatever the length of the uniserial portion, however, the proximal end of a *Dimorphograptus* is distinguishable from that of *Akidograptus* or *Cl. törnquisti* by the upward direction of growth of th1^1, even from its commencement (Elles and Wood, 1908, p. 347) and so far as the first two thecae of the rhabdosome are concerned, the development is of Monograptid type.

COMPARISON OF *DIMORPHOGRAPTUS*, *AKIDOGRAPTUS*, AND *RHAPHIDOGRAPTUS*.

We have thus three "heteroprionidian" graptolites, in each of which th1^2 has been lost, yet each presents some distinctive features in the resulting appearance of the proximal end. To a large extent these are a natural consequence of differences in the proximal end of the ancestral forms from which they have been derived, and it is evident that in early Silurian times various types of biserial graptolites underwent development along the Monograptid trend. The three genera now recognized may be defined as follows :—

Dimorphograptus Lapworth, 1876.

(Genolectotype: *Dimorphograptus elongatus* Lapw., 1876; Bassler, 1915, p. 441.)

Rhabdosome biserial distally, uniserial proximally, with loss of $th1^2$ and generally further thecae of the secondary series. Initial development as in *Monograptus*, $th1^1$ growing from its commencement in an upward direction.

Length of uniserial portion variable; thecae may show introduction of new thecal types.

Biserial portion with partial or complete septum; thecae of various Diplograptid types.

Akidograptus Davies, 1929.

(Genotype: *Akidograptus ascensus* Davies, 1929.)

Proximal end of rhabdosome characterized by reduction or loss of $th1^2$, but on account of shortening of $th2^2$ there is no apparent uniserial portion; $th1^1$ retains the primitive downward direction of growth of its initial portion; development of $th2^1$, $th2^2$, etc., is typically accelerated.

Median septum partial or complete; thecae of various Diplograptid types.[1]

Rhaphidograptus gen. nov.

(Genotype: *Climacograptus törnquisti* Elles & Wood, 1906.)

Proximal end of rhabdosome uniserial, characterized by loss of $th1^2$; $th1^1$ retains the primitive downward direction of growth of its initial portion; $th2^2$ is of normal length, and there is no marked acceleration in the development of the early thecae of either series.

Biserial portion with partial (? or complete) septum; thecae of Climacograptid type.

There seems no reason to restrict the genus to those Climacograptids, in which only $th1^2$ has been lost, and should further stages be found to make it desirable it might be given the same latitude in this respect as the parallel genus *Dimorphograptus*.

References.

Bassler, R. S. 1915. "Bibliographic Index of American Ordovician and Silurian Fossils," *U.S. Nat. Mus. Bull.*, 92.

Bulman, O. M. B. 1932. "Notes on the Evolution and Morphology of Certain Graptoloidea," *Arkiv för Zoologi*, 24A, No. 13.

Davies, K. A. 1929. "Notes on the Graptolite Faunas of the Upper Ordovician and Lower Silurian," Geol. Mag., LXVI, 1–27.

---

[1] Davies states that they "vary in shape between those of *Climacograptus* and *Orthograptus*", but it would seem more correct to substitute *Glyptograptus* for *Climacograptus* in this definition. It is difficult to be certain, from the published figures, of the structure of the proximal end in *Akidograptus priscus* Hsü (1934) and the thecal characters are not very clear, but if $th1^2$ is absent here and the thecae are truly Climacograptid, it would be natural to transfer this species to *Rhaphidograptus*.

Elles, G. L. 1922. "The Graptolite Faunas of the British Isles," *Proc. Geol. Assoc.*, xxxiii, 168–200.
—— and E. M. R. Wood. 1906. "Monograph of British Graptolites," *Palaeont. Soc., London*, pt. v.
—— —— 1908. *Ibid.*, pt. vii.
Hsü, S. C. 1934. "The Graptolites of the Lower Yangtze Valley," *Mon. Nat. Research Inst. Geol. (Acad. Sinica)*, ser. A, vol. iv.
Lapworth, C. 1876. "On Scottish Monograptidae," pt. iv, Geol. Mag., 544–552.
Törnquist, S. L. 1897. "On the Diplograptidae and Heteroprionidae of the Scanian *Rastrites* Beds," *Kgl. Fysiogr. Sällsk. i Lund. Handl.*, n.f. viii, 1–24.
Wiman, C. 1895. "Über die Graptolithen," *Bull. Geol. Inst. Upsala*, ii, pt. 2, no. 4.

The Geology of an Area in the Kavirondo District, Kenya Colony.

By William Pulfrey, Geology Department,
University of Sheffield.

1. Introduction.
2. Situation and Topography.
3. Outline of Geology.
4. Details of Geology.
   (a) The Sedimentary Series.
   (b) The Igneous Intrusives.
      (1) The Main (Maragoli) Granite.
      (2) Minor Granite Bosses.
      (3) Acid and Intermediate Dykes.
      (4) Basic Dykes.
      (5) Ultrabasic Dykes.
5. Thermal Metamorphism, Metasomatism, and Pneumatolysis.
6. Dynamic Metamorphism.
7. Summary and Conclusions.
8. List of Works Referred to in Text.

1. Introduction.

PREVIOUS to 1931 the Kakamega area, in the Central Kavirondo Reserve of Western Kenya, was almost unknown from a geological standpoint. Gregory (1,[1] 1921) had made brief references to it, but no detailed geological or petrographical examinations had been made of any part. Following on the discovery there in 1931 of alluvial and reef gold, and subsequently the entry of mining companies into the field, a great deal of geological research has been carried out.

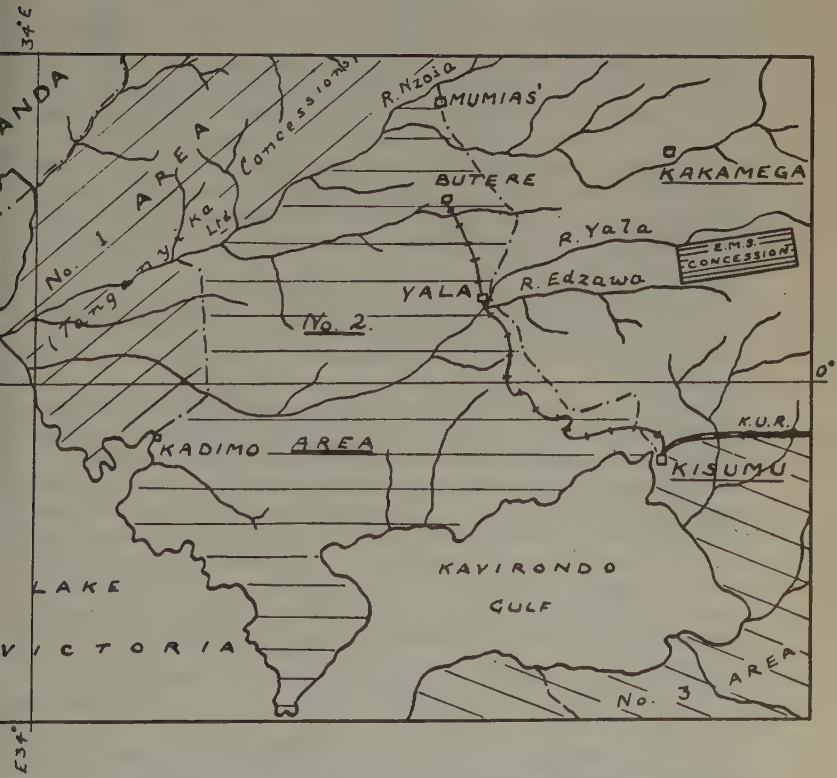
During 1934–5 the author, whilst mapping a 35 square miles concession (originally owned by the Eldoret Mining Syndicate—E.M.S.—and subsequently examined by East Africa Concessions, Ltd.),

[1] The numbers (1) to (12) refer to previous publications, listed on p. 38.

was enabled to make a detailed field examination of a part of the area, and later to examine a series of thin slices of the rocks concerned. The account now given[1] is based on facts accumulated during these investigations.

2. Situation and Topography.

The concession is situated on the northern slope of the Yala-Edzawa divide, about 16 miles N.N.E. of Kisumu, on the Kavirondo Gulf. The area is easily reached by indifferent roads from either Kisumu or Kakamega, or from the east by roads from Nairobi and Eldoret. It is profusely supplied by perennial streams, and



TEXT-FIG. 1.—Sketch plan of part of the Central Kavirondo District, showing the position of the E.M.S. Concession. Scale 1 : 1,000,000.

---

[1] By permission of Sir Robert Williams and Co., London. My thanks are due to F. E. Studt, Esq., of that company, and to Professor W. G. Fearnsides, F.R.S., for their kindness in reading through the typescript, and for the suggestions they offered.

the vegetation is thick and abundant, whilst east of the River Itsawa, the area consists mainly of dense forest. The exposures are on the whole not good, and as a result some lines of evidence must remain incomplete. The best and most prolific exposures occur along the stream courses and on some of the thicker grit lenticles where they cross the divides. Otherwise many of the divides are completely barren of exposures.

3. Outline of the Geology.

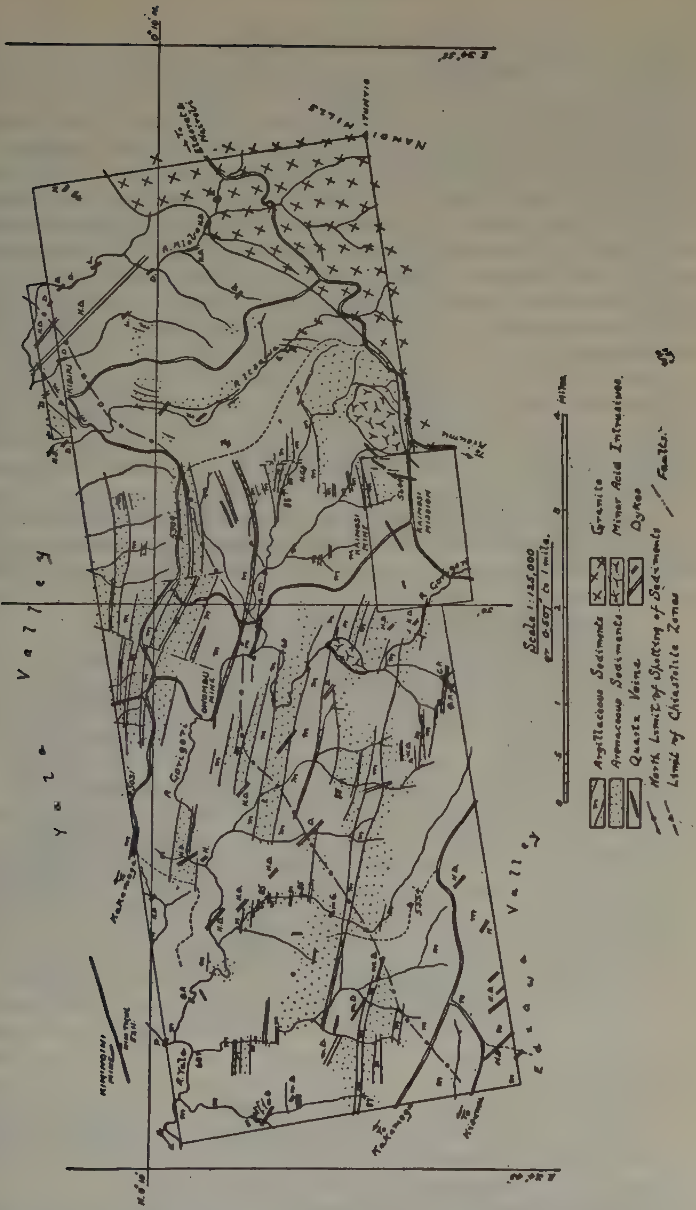
The area occupied by the concession consists mainly of sediments of Muva-Ankolean age, associated with intrusives of several ages, of which the major is the Maragoli granite in the south-east. The granite is part of a large batholith which underlies the greater part of the Nyanza Province of Western Kenya, and the sediments are a marginal part of an extensive roof-pendant resting on the granite, and stretching from the Kakamega Escarpment, east of Kakamega, through Butere and Yala, to Kadimo on Lake Victoria (2, Murray-Hughes, 1933, endplate ; and 3, 4, Government geological maps).

The other igneous rocks consist of two pre-Main-granite bosses, a few acid dykes, many basic and some ultrabasic dykes. The basic dykes occur in marked co-linear groups in the western part of the area.

The gold in the area appears to be an associate of the late phases of the granite intrusion, and occurs mainly in quartz veins and stringers and occasionally in low-grade sulphide impregnations.

The structure of the area is simple and consists of two folds separated by a long " flat " intermediate limb. The two folds are subsidiary folds in the major folds of the Kakamega area (5, Kitson, 1932, p. 5), and they are themselves gently folded (and on occasion sharply plicated) in a manner which can be shown only on large-scale maps. Dips are usually steep, frequently more than 60 degrees, and very often approaching the vertical, and incline most often to the north. Several steep dips to the south were also noted, but appear to be local inversions. Few faults have been mapped, and it is probable that many exist which cannot be mapped owing to indifferent exposure. The two most noticeable faults are (1) the Akwirangi Fault (N.E. of Owombu), striking N.N.E. and throwing about 650 feet to the W.N.W., and (2) the Muhudu Fault (1½ miles east of Owombu), striking N.N.W. and throwing 600 feet to the west. The large white quartz vein near Kaimosi Mission is cut and lenticularized by two relatively small thrusts.

The Recent history of the area is one of comparatively minor oscillations of level, which have led to the incision of the Nyanza peneplain. The oscillations are marked by two sets of river terraces, one set 60–70 feet above present river level, and the other 10–15 feet.



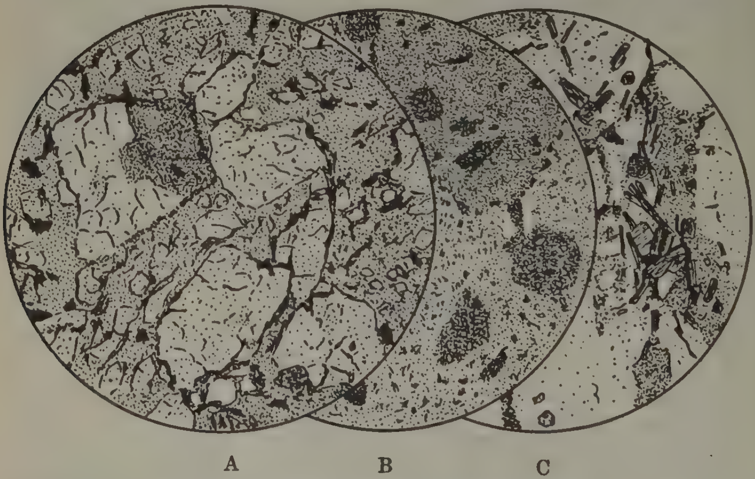
TEXT-FIG. 2.—Geological Map of the E.M.S. Concession, Central Kavirondo, Kenya. Many small rivers are omitted. Symbols used to indicate types of dykes: mG = micro-granite, QP = quartz porphyry, GP = granite porphyry, HG = hornblende granophyre, P = porphyrite, D = dolerite, HD = hornblende diorite, mD = microdiorite, L = lamprophyre, H = hornblende porphyrites and hornblendites, E = actinolitic greenstone.

4. Details of Geology.

(*a*) THE SEDIMENTARY SERIES.

The sedimentary series consists of an alternation of argillaceous and arenaceous types, occurring in roughly equal proportions, and is readily comparable with the North Mara Series of sediments, recently described from the Musoma area of Tanganyika (6, Stockley, 1935, p. 18). Almost all varieties exist and gradations are not uncommon. The argillaceous members are mainly mudstones, whilst shales are rare. Sandstones are also uncommon, and occur only in thin impersistent lenses or bands. The commonest members of the arenaceous series are typical felspathic grits, grading into agglomeratic grits, which are locally abundant. They may well be compared with the grits and conglomerate of the pre-Cambrian Ingletonian Series of West Yorkshire (7, Rastall, 1906, p. 92 *et seq.*), where, however, the grits are often rich in muscovite, or with the pre-Cambrian Helmeth grits of Shropshire (8, Cobbold and Whittard, 1935, p. 353).

A good example of the normal grit occurs where the River Gorigori cuts the western Kaimosi Mission boundary. Under the microscope (slide K 5, Text-fig. 3, A) it shows the following features: Texture



TEXT-FIG. 3.—Sediments from the E.M.S. Concession. × 19. A: Grit, ford on the R. Gorigori, west boundary, Kaimosi Mission. Quartz and some felspar grains, with occasional compound grains, in an ill-sorted quartz-sericite matrix. Slide K 5. B: Spotted schist; R. Kamalungwich. Large granular spots composed of the degradation products of cordierite, and abundant ragged poeciloblastic plates of biotite. Matrix rich in quartz and sericite. Slide K 37. C: Biotite grit-hornfels, R. Kamalungwich, 1½ miles east of Kaimosi Mine. Large recrystallized quartz grains with abundant clusters and flakes of biotite. Matrix quartzitic, recrystallized. Slide K 64.

fragmental. Quartz grains abundant, many macroporphyroblasts and very abundant smaller fragments. The margins of the larger crystals are markedly crenulate and sometimes irregular. The larger grains are always recrystallized. Felspars are not common, and comprise a few broken crystals of alkali felspars, including rare microcline. Plagioclase fragments are rare. The matrix is granular, rich in quartz grains and sericite flakes, often in trains, and with occasional ragged aggregates of greyish-green fibrous chlorite flakes. There are occasional zircon crystals and sporadic iron ores. Other examples (e.g. slide K 1, Adit No. 1, Owombu Mine) have, in the hand-specimen, a typical hornfelsic appearance, but in the slide are very similar to the example described above. Many are found to contain composite grains of quartz and felspar, associated in a granitic manner.

Under metamorphic influence the chlorite and sericite of the grits have reacted to form biotite, giving rise to biotite grit-hornfelses. A specimen, from ½ mile N.E. of Kaimosi Mission (slide K 64, Text-fig. 3, C) shows the following features: A typical slightly felspathic grit, with abundant biotite, pleochroic from deep brown to a pale fresh brown. The flakes of biotite occur scattered in the matrix, but also typically edge the quartz grains. The matrix is considerably recrystallized to a quartzitic type and contains no trace of sericite. The agglomeratic grits are essentially similar to the grits, except that they contain some proportion, ranging from few to many, of rock fragments of many types, including granites, acid hypabyssal rocks and coarse and fine grained sediments. The fragments range in size from the normal grit grade to 1 foot diameter; they are angular or sub-angular, sometimes rounded.

Locally well-defined conglomerates are found, and in the central part of the area (at the loop of the River Gorigori) there is a development of coarse agglomerate. An unusual type, which for convenience I have called "pseudo-conglomerate", and which has given rise to much dispute, occurs most markedly in the low-grade ore-body at Kibiri, and consists of round or oval boulders of all sizes, scattered in what appears, at first sight, to be an igneous matrix. The matrix, however, in thin sections, is found to be a normal grit, though sometimes it contains shredded lava fragments, suggesting that this type may, in some cases, have an origin comparable with that suggested by A. W. Groves (9, 1931, p. 47) for "lava conglomerates" occurring near Kisii in the Southern Kavirondo, viz. the covering by or irruption of lava into pebble or boulder beds, or cementation by emanations from adjacent lavas.

These peculiar types are no doubt equivalents of what have popularly been called the "Kakamega Conglomerates". These are of widespread occurrence, and have led to acute controversy between two schools of thought, the one holding that they are true conglomerates and the other that they are intrusion breccias. Murray-Hughes (2, 1933, p. 5) states that they occur in east-west oriented lenses, each with its characteristic suite of pebbles, and on the index of plate 2 (*ibid.*, geological sketch plan) states that they are "conglomerates (composed of volcanic material but not an agglomerate)". This opinion follows on that put forward by Sir Albert Kitson (5, 1932, p. 6). Some observers, bearing in mind the examples of intrusion-brecciation and complex intrusion which occur in parts of the Kavirondo region, have been led to question the opinion. But as far as I have seen the hypothesis of a clastic, possibly part pyroclastic origin, is much more acceptable. An example of this type, from a locality near the Kimingini Mine, submitted to me for microscopic examination, proved to be a pebble of hornblende-biotite-granite in a matrix of sheared chloritic tuff.

Metamorphism by the Main granite has led to the production of a variety of types in the sediments. The metamorphic aureole is wide (Text-fig. 2)—2 to 3 miles—and the effect is most marked in the production of cordierite and hornfels textures in the argillaceous sediments. Chiastolite is rarer, and occurs only in a band at the limit of the cordierite zone, stretching from the centre of the area to Kibiri, in the west in a band south of the limit of spotting, and at Kibiri in a band north of the limit of spotting. Cordierite is only rarely developed in the finer grades of the grits, and as a rule the equivalent metamorphism is marked in the grits by the development of biotite. Higher grades than this were not observed, and nearer the granite the main metamorphic effect is marked by the production of hornfelses and the intense formation of white micas in some of the sediments.

The conditions under which the sediments accumulated affords matter for considerable speculation. The mudstones are normal and the grits themselves are not unusual except that they never exhibit current-bedding. The coarser arenaceous types, the agglomeratic grits, with their abundant scattered or crowded rock fragments, are anomalous, and cannot be regarded as normal sediments. The absence of lavas, except as shreds in the pseudo-conglomerates, makes it all the more difficult to account for them. It seems that they must be considered either as true partly agglomeratic rocks derived from acid volcanoes, not now known, or that they represent the degradation products of ancient brockrams.

(*b*) THE IGNEOUS INTRUSIVES.

(1) *The Main* (*Maragoli*) *Granite.*

Only a small part of the granite is seen in the area, but it is interesting for the variation which it exhibits. The Maragoli Granite, a member of the Younger Granite Series of East Africa, has been described by A. J. P. Walter (10, 1933) as a monzonite, but microscope examination of specimens from this area prove it to be a granite. The varieties along the margin in the south-east range from hornblende-microcline-granite in the north, through biotite-granophyre, to ferromagnesian-poor biotite-granite in the south, whilst within the mass the granite is a coarsely porphyritic hornblende-granite. Further west the marginal variety is a highly porphyritic hornblende-granite, the felspar phenocrysts having crude fluxional arrangement; cognate xenoliths are abundant and intrusion breccias occur.

As a rule the marginal granite is comparatively free from xenoliths, a fact correlative with the low degree of metamorphism associated with the intrusion.

Mineralization is not marked. Small pegmatite veins are present, but show little trace of pneumatolytic minerals, and there is no greisenization or kaolinization.

(2) *Minor Granite Bosses.*

Two smaller granite bosses are present in the area. The larger of these, of pre-granite age, occurring just east of Kaimosi Mission, is an alaskitic granite, with little or no microcline and almost no dark minerals. The texture is very variable, ranging from granitic, through porphyritic types, to microgranite.

The second boss, an "inlier", cut into by the River Gorigori at Ikobero, exhibits differentiation. The centre of the mass is a hornblende-biotite-granite, the hornblende being entirely actinolitic, whilst marginally there is a broad band of porphyritic hornblende-biotite-granophyre, again actinolitic. On the west there is a narrow, still more basic zone, of highly altered quartz-diorite. The granite (slide K 31, Text-fig. 4, A) has normal texture. The felspar is mainly very altered, but remains of basic oligoclase crystals can be traced. The amphibole is fibrous actinolite, and the biotite occurs in small plates, pleochroic from golden brown to deep brown. It is often partly or entirely replaced by chlorite, as is the actinolite also.

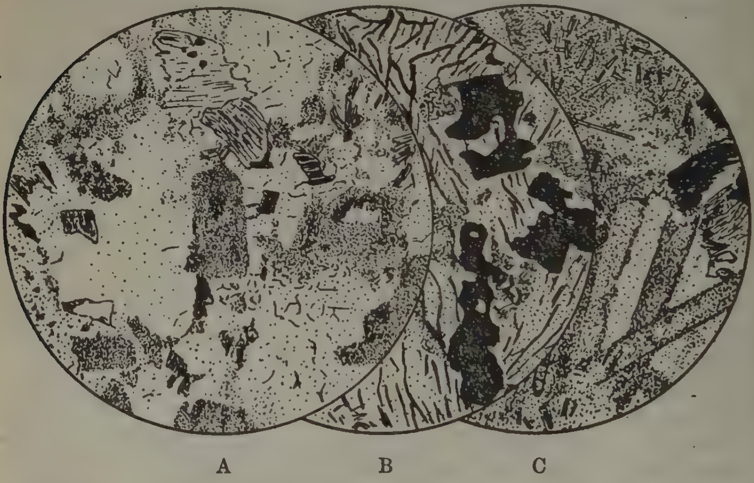
The granophyre (slide K 10) is markedly different from the granite, since it contains very abundant phenocrysts (ranging up to 3 and more mms. diameter) consisting usually of fibrous iron-poor actinolite, often with partly decussate arrangement. Biotite is fairly abundant in thick plates (± 0·35 mm. diameter, and often almost as thick), pleochroic from very pale brown to a deep foxy brown. It is usually freely grown, but sometimes parallels the actinolite. The matrix is a crude graphic intergrowth of quartz and altered orthoclase with occasional oligoclase laths. Apatite, in slender prisms, occurs in the matrix.

The diorite (slide K 24, Text-fig. 4, C) has normal texture. The felspars are long laths of altered acid andesine and less abundantly altered alkaline felspars. There is a small proportion of interstitial quartz. There is no biotite, and the ferromagnesian mineral is fibrous actinolite. Chlorite and sericite occur sporadically. Apatite in stout prisms is common, as is also ilmenite, often partly leucoxenized.

There is no original hornblende in any part of the boss, and the presence of actinolitic pseudomorphs suggests that originally the whole was an augite rock. The alteration was produced by the heating effect of the Main granite, which lies below the Ikobero boss at no great depth.

(3) *Acid and Intermediate Dykes.*

Acid dykes are few and small, and include quartz-porphyries, granite-porphyry, and one example of riebeckite-biotite-microgranite. They have a regional north-west trend as a rule. The micro-granite is the only soda-rich rock which has been discovered in the area. It is a typical microgranite (slide K 13) with scattered orthoclase phenocrysts. The matrix is very rich in quartz. The coloured minerals are also abundant, occurring in ragged aggregates and poorly shaped crystals. The most abundant is riebeckite in small crystals, often tending to prismatic habit; it has typical low extinction angles, and absorption X > Z, with pleochroic scheme X, deep bright green Z, dull light green or yellowish green. The



Text-fig. 4.—Igneous Rocks from the E.M.S. Concession. × 19. A: Granite; Ikobero Boss, slide K 31. Flakes and plates of biotite and chloritized biotite, with aggregates of fibres and flakes of actinolite. Cloudy felspar phenocrysts. Quartz abundant, accessories few. B: Hornblendite; Odango's River, 5 miles W.S.W. of Kaimosi Mission, slide K 48. Mainly composed of thick poeciloblastic plates of green hornblende, with spongy magnetite growths, cloudy felspars, and pools with actinolite needles. C: Diorite; Ikobero Boss, slide K 24. Considerably altered lathy plagioclase, and less common patches of altered alkaline felspar. Abundant fibrous and flaky actinolite, associated with a little chlorite. Apatite common, usually in stout prisms, and ilmenite also common, in large platy crystals, often showing an appearance of parallel shredding.

biotite is less abundant than the riebeckite, with which it is often intergrown, and occurs in small thick plates, pleochroic from straw to very deep brown tints.

Intermediate dykes are rare, and two examples only, one a porphyrite and the other a hornblende-granophyre, are known.

(4) *Basic Dykes.*

Basic dykes are abundant in the western half and in the eastern quarter of the area, though the intervening portion is entirely devoid of them. In the eastern part the dykes occur in an irregular swarm, with strikes varying from north-west to north, and include dolerites, hornblende diorites, and two examples of lamprophyres. The western dykes occur in three well-defined co-linear groups and in an ill-defined swarm in the south-west. They comprise dolerites and diorites, and in the western curvi-linear group alone, microdiorites. Most of these types contain some proportion of interstitial quartz, and on occasion well-defined micrographic mesostasis, notably in the large dyke east of Kibiri, which approaches a granophyre type.

Most of the dolerites are partly altered, with clouding of the felspars, conversion of augite to actinolite, and the formation of epidote. And all gradations from almost unaltered dolerite to completely actinolized types may be found, and it is a moot point whether or not all the diorites may actually be altered dolerites. The presence of the hornblende-microdiorite, however, which is quite fresh, lends some doubt to this hypothesis.

Occasional examples are considerably altered. One, almost at the granite contact in the River Mlobo, has been converted into a green schist with its hornblende and felspars mainly replaced by epidote and chlorite. Another example has become a quartz-actinolite-epidote aggregate retaining none of its original texture, whilst a third has had its felspar entirely replaced by coarsely granular epidote.

Only one of the lamprophyres was examined under the microscope, and was found to be an actinolitic quartz-minette, with abundant deep brown biotite, often associated with actinolitic growths, in an orthoclase-rich matrix containing a little oligoclase. Quartz is fairly common interstitially, whilst apatite and magnetite occur as rare accessories.

In addition to the above there are occasional dykes of actinolitic greenstone, derived by alteration of unknown basic types. They are totally recrystallized, consisting mainly of matted aggregates of large and small actinolite needles, with interstitial chlorite, in parts very abundant and in large excess of the actinolite.

The age of these basic dykes is somewhat doubtful. Previously there has been a tacit assumption that they are of post-Younger granite age, and no doubt this is borne out by field data in some cases (2, Murray-Hughes, 1933, p. 5). But the almost constant thermal alteration of the dolerites, the intense alteration of occasional dykes near the granite contact and the presence of a definitely pre-granite dolerite in a small roof-pendant in the upper River Mlobo indicate that in this area at least some of the basic dyke suite are of pre-granite age, and may perhaps be correlated with the igneous epoch during which the Ikobero boss was intruded. A similar division into Old and Young dolerites has been observed in the Sanza area of Tanganyika (11, Wade, 1934, pp. 10 and 33 (Oates)), where the younger dolerites are quite fresh, whilst the older show every gradation from dolerites to epidiorites and micro-amphibolites. In the Kakamega area against this division must be placed the fact that almost none of the dykes show signs of dynamic metamorphism, although from microscope examination of the granite it is evident that some proportion of post-Main granite shearing did occur.

(5) *Ultrabasic Dykes.*

Ultrabasic dykes are uncommon. They have the same regional strike as the basic suite, and are all hornblende-rich rocks, comprising basic hornblende-porphyrites and types verging to hornblendites. The latter are rare, and in the hand-specimen appear to consist mainly of large, thick plates of poecilitic hornblende. In thin slice (slide K 48, text-fig. 4B) the plates of hornblende are seen to enclose abundant cellular patches of magnetite and patches of clear felspar. The hornblende has absorption $Z > Y > X$ and has rather weak pleochroism, Z pale blue-green, Y pale green, X yellowish-green. The matrix is almost negligible, containing abundant small hornblende prisms. Although the hornblende has usually well-developed cleavages, the texture and constitution of the rock suggest formation from an original augite type.

The porphyrites (e.g. slide K 54) are a somewhat less basic type gradational from the hornblendites, and have abundant large phenocrysts as well as microphenocrysts of bright fresh green hornblende, often with a bluish tinge. The felspar is not abundant, and consists of clear or slightly cloudy pools of untwinned recrystallized plagioclase. Ilmenite altering to leucoxene is abundant.

5. Thermal Metamorphism, Metasomatism, and Pneumatolysis.

Brief reference to some of the metamorphic effects has been made above. The thermal aureole of the granite is unusually wide, reflecting the gentle dive of the granite contact and the shallowness of the Kakamega roof-pendant. The approximate margin of the aureole is readily delimited by the northern margin of the zone of spotting in the argillaceous sediments (Text-fig. 2). North of this metamorphism is still shown by the development of biotite, but the exact limit of the mica zone is not readily determinable in the field.

The commonest types produced are spotted mudstones or schists, e.g. slide K 37 (Text-fig. 3, B), from the River Kamalungwich, 1 mile north-east of Kaimosi. This is a cordierite-biotite-schist ; the matrix is fine-grained, rich in quartz, with abundant oriented sericite flakes. The mica occurs in ragged poeciloblastic plates, in an early stage of formation, whilst the cordierite, in typical poeciloblastic crystals, is now replaced completely by chlorite-sericite aggregates. This description fits generally the majority of the types, except that occasional examples have developed in them large (e.g. 8 mm. long) crystals of chiastolite, now replaced by sericite and quartz.

In those sediments nearer the granite the biotite takes on well-defined characters, and the corrosion and recrystallization of quartz is more marked. In the fine-grained sediments hornfelsic textures are developed with decussate arrangement of the biotite. At Kaimosi and further west high grades are developed, probably in originally highly sericitic rocks, and due in part to dynamic as well as thermal metamorphism. They include quartz and sericite schists, as well as more normal phyllites and sometimes spotted types.

The highest grade of metamorphism was observed in an enstatite-biotite-schist from the River Mlobo, near the southern lobe of the granite. This rock (slide K 73), produced from an arenaceous member of the series, contains abundant biotite, and comparatively large (1 mm.) crystals of pale green enstatite in a highly recrystallized quartzitic matrix containing relict quartz and felspar grains.

Metasomatism.—Metasomatic effects are not marked. There is some proportion of silicification, especially, in the grits (cf. Kitson, 1932, p. 6), and with this may be correlated the abundant veining and gashing by quartz. It is in these veins that the gold of the area is usually found. Other ore deposits, as the auriferous mispickel and pyrite of the Kibiri ore-body, and small proportions of lead, copper, and silver ores found in association with gossans at Kaimosi Mine, may similarly be ascribed to metasomatic changes.

Pneumatolysis.—Pneumatolytic effects of the more spectacular kind are almost entirely absent. Marked tourmalinization does not occur and quartz-tourmaline veins, which occur in some parts of the Kakamega area (5, Kitson, 1932, p. 14), are not present here. But in several of the finer grained sediments, even far out in the metamorphic aureole, feeble developments of minute crystals of tourmaline can be observed. W. H. Wilcockson (12, 1934) observed similar tourmaline in the Kibiri mudstones, but considered it to be allogenic.

In grits near the granite the development of large plates of a white mica sometimes marks the effect of pneumatolysis.

6. Dynamic Metamorphism.

Dynamic metamorphism occurred at two distinct periods at least; one, the most marked, previous to, and the other later than, the intrusion of the Main granite. The earlier phase, during which the poor cleavage of some of the argillaceous sediments, especially in the north-west part of the area, was developed, was coeval with the main folding and was only moderately severe in its effects. The later phase, of still less intensity, is marked by the displacement and contortion of quartz veinlets, by slight crushing of the granite, by the schistification of the spotted sediments in the aureole, and by the conversion in them of cordierite and chiastolite to degradation products, sericite, chlorite, and quartz.

7. Summary and Conclusions.

1. The area described is part of the dissected peneplain in the Central Kavirondo District of Western Kenya.
2. The greater part of the area is occupied by arenaceous and argillaceous sediments of Muva-Ankolean age.
3. The sediments are part of a large roof pendant resting on the extensive Nyanza granite batholith. The metamorphic effects of the granite are described.
4. The sediments are also invaded by two pre-Main granite bosses, as well as dykes of various types, those of basic type predominating. Some of these are of pre-granite, some post-granite age.
5. Gold occurs in the area as a metasomatic phase of the end-stages of the granite intrusion.

List of Works Referred to in Text.

(1) Gregory, J. W. 1921. *The Rift Valleys and Geology of East Africa*, London.

(2) Murray-Hughes, R. 1933. "Notes on the Succession, Tectonics, and Economic Geology of the Western Half of Kenya Colony," *Report No. 3, Geological Survey of Kenya*, Nairobi.

(3) Kenya Government. 1933. *Geological Map of the Kakamega Area*, Sheet $\frac{\text{North A 36}}{\text{W}}$ 52 and 53, Africa, 1 : 62, 500. Mining and Geological Department, Nairobi,

(4) —— 1935. *Annual Report for 1934*. Mining and Geological Department, Nairobi. Endplate (map).

(5) Kitson, Sir A. E. 1932. *Interim Report on the Kakamega Goldfield*, Nairobi.

(6) Stockley, G. M. 1935. "Outline of the Geology of the Musoma District," *Bulletin No. 7, Geological Survey of Tanganyika*, Dar-es-Salaam.

(7) Rastall, R. H. 1906. "The Ingletonian Series of West Yorkshire," *Proc. Yorks. Geol. Soc.* (New Series), xvi, pt. i, 87.

(8) Cobbold, E. S., and Whittard, W. F. 1935. "The Helmeth Grits of the Caradoc Range, Church Stretton: their bearing on part of the Pre-Cambrian Succession of Shropshire," *Proc. Geol. Assoc.*, xlvi, pt. iii, 348.

(9) Groves, A. W., in E. J. Wayland. 1931. *Report on a Geological Reconnaissance of the Southern Kavirondo*, Nairobi.

(10) Walter, A. J. P. 1933. "Prospecting in Kenya by Earth Augering," *Mining Mag.*, 49, no. 6, 329.

(11) Wade, F. B. 1934. "The Saragura and Associated Gold Occurrences of the Mwanza area with Petrographical Notes on the Specimens Collected by F. Oates," *Geological Survey of Tanganyika, Short Paper No.* 12, Dar-es-Salaam.

(12) Wilcockson, W. H. 1934. *Report on the Series of Specimens from the Kakamega Goldfield*, private report to Sir Robert Williams and Co.

On Bababudanite, a Soda-amphibole from the Banded Ferruginous Quartzites of Mysore, India.

By Charles S. Pichamuthu, Assistant Professor of Geology, University of Mysore, India.

1. Introduction.

BANDED ferruginous quartzites form a conspicuous feature of many of the outcrops of Dharwar schists in Mysore. Because of their much greater hardness than the associated chloritic and hornblendic schists, these quartzites have withstood the action of weathering agencies better, and form prominent hill ranges in the schist belts. One such important range is the Bababudan hills in the Kadur district, comprising some of the highest peaks in the Mysore State, several of which are over 6,000 feet above sea-level.

The Bababudan hills are mainly composed of thick beds of haematite and magnetite quartzites which are separated by bands of chloritic and talcose schists. The high angles of dip and the intensely folded nature of these quartzites are evidences of the great disturbances to which these rocks have been subjected. The complicated tectonics of this area have not yet been satisfactorily elucidated, as geological work on these hills is heavily handicapped by the dense jungles infested with wild animals, and the thick soil cap which obscures the disposition and relationship of the rocks. The ferruginous quartzites overlie an epidiorite flow of spilitic affinities. A few dykes of epidiorite, some of which are tourmaline-bearing, have invaded the quartzites.

2. Previous History.

It was in the year 1907 that this amphibole was discovered by Mr. Sampat Iyengar in the banded ferruginous quartzites of the Gangagiri branch of the Bababudans. He refers to the mineral as riebeckite and has given the following brief account of its properties. "The mineral riebeckite occurs in radiating prismatic aggregates and in scattered patches having a strong pleochroism from Prussian blue to purple and yellowish green. The blue colour prevails when the light rays are vibrating parallel to the ether axis $\mathfrak{a}$, purple when parallel to the $\mathfrak{b}$ axis, and yellowish green when parallel to the $\mathfrak{c}$ axis. The extinction angle is about 7° and the optical character of the mineral appears to be positive. The specific gravity is 3·18. An analysis of the mineral, however, yielded 12·11 per cent of MgO, which is rather high for riebeckite. Probably this is a variety of the mineral rich in magnesia."[1]

The mineral was examined by Dr. Smeeth the same year, and he published a chemical analysis. Except for the statement that $\mathfrak{a}$ made an angle of 7–9° with the crystallographic axis c, there were no new optical data beyond what were given by Sampat Iyengar. He left the optical sign doubtful, since he could not obtain satisfactory figures because of absorption and dispersion. He considered the mineral as a variety of riebeckite and gave it the name *bababudanite.*[1] From the analysis (which is quoted in Table I), he obtained the following formula for the mineral :—

---

[1] P. Sampat Iyengar, "Report on the Geology of parts of Hassan and Kadur Districts," *Rec. Mys. Geol. Dept.*, ix, 1908, 73.

$$2NaFe(SiO_3)_2.(FeMg_3)(SiO_3)_4$$

Bababudanite was reported to occur only in the western portion (the Gangagiri branch) of these ranges by Sampat Iyengar. In 1920, B. Jayaram[2] observed the occurrence of this mineral in the neighbourhood of Attigundi (13° 36′ : 75° 44′) and in 1932, the writer obtained very good specimens near Kemmangandi (13° 33′ : 75° 45′) and Kalhatti (13° 31′ : 75° 47′) on the eastern slopes of the Bababudans. The mineral is distributed sporadically in the ferruginous quartzites as well as aggregated into compact layers associated with magnetite and quartz.

3. BABABUDANITE.

(i) *Physical Characters.*—Bababudanite is a shining black mineral, possessing an almost adamantine lustre when perfectly fresh. The mineral frequently appears dark brown, but when examined under the lens, this colour is seen to be due to haematite or limonite which is deposited on the surface and along the cleavages.

The crystals are prismatic with an acicular habit. Sometimes they form fibrous bands which are replaced by quartz.

Perfect 110 cleavages intersect at an angle of 126°. The specific gravity of the mineral is 3·31. This was determined by suspending a few grains in a solution of methylene iodide diluted very slightly with benzene. The specific gravity of the liquid was then found by using a pycnometer.

(ii) *Chemical Composition.*—Since the analysis published by Smeeth totals only to 97·68, it was considered necessary to obtain a new and more accurate analysis. This was kindly made for me by Mr. W. H. Herdsman of Glasgow.

Smeeth obtained the mineral for analysis by the following method. The amphibole-bearing ferruginous quartzite was crushed and the magnetite removed by a magnet ; the residue was treated with hydrochloric acid to remove the remaining oxides of iron, and then a heavy liquid was used to separate the amphibole. The writer tried this method but an examination of the concentrate showed that quartz was associated with the bababudanite, not so much as inclusions but as fragments of grains moulded on the amphibole, and so this procedure was rejected. The same reason rendered heavy liquid separation also unsuitable for obtaining a pure concentrate of the mineral. Recourse was therefore had to the tedious method of hand picking. The rock was crushed and the fine dust got rid of by sieving. The magnetite was removed by a magnet, and the quartz was separated by using bromoform. The heavy residue was placed in small portions under a lens, and the mineral picked out with a moistened mounted needle. Since the amphibole was often of hair-like fineness, the procedure was extremely slow and it took nearly two months to collect just enough material for a chemical analysis. The results of this analysis are given in column I of the following table. For purposes of comparison, analyses of crocidolite, rhodusite, and crossite are placed alongside. In column II the only other analysis of bababudanite is given.

---

[1] W. F. Smeeth, " Notes on a variety of Riebeckite (Bababudanite) and on Cummingtonite from the Mysore State," *Rec. Mys. Geol. Dept.*, ix, 1908, 86.

[2] B. Jayaram, " Progress Report on work done during the field season of 1919–1920," *Rec. Mys. Geol. Dept.*, xx, 1923, 41.

TABLE I.

	I	A	B	C	D	II
SiO_2 .	49·80	51·15	54·01	55·03	55·02	54·48
Al_2O_3 .	1·56	—	0·23	0·49	4·75	2·10
Fe_2O_3 .	18·62	14·92	15·70	15·47	10·91	15·79
FeO .	10·59	9·80	9·42	7·39	9·46	5·02
MgO .	9·30	10·80	10·01	11·48	9·30	12·11
CaO .	0·45	1·12	1·52	0·98	2·38	1·04
Na_2O .	8·80	6·52	6·22	6·38	7·62	6·34
K_2O .	tr	0·63	0·35	0·80	0·27	0·32
H_2O .	0·65	4·77	2·25	1·98	—	0·40
MnO .	—	0·30	0·14	—	tr	0·08
	99·77	100·01	99·85	100·00	99·71	97·68

I. Bababudanite. Kemmangandi, Bababudan Hills, Mysore. Analyst, W. H. Herdsman.
A. Crocidolite. Dochfour, Scotland. Quoted from Dana's *System of Mineralogy*, sixth edition (1911), p. 400.
B. Rhodusite. Asskys River, Minussinsk District, Siberia. Quoted from *Journ. Chem. Soc.*, 94, 1908, Abstracts, part ii, 401.
C. Rhodusite. Rhodus Island. Quoted from First Appendix to Sixth Edition of Dana's *System of Mineralogy*, p. 29.
D. Crossite. Berkeley, California. Analyst, W. S. T. Smith. *Ibid.*, p. 20.
II. Bababudanite. Gangagiri branch, Bababudan Hills, Mysore. Smeeth, *Rec. Mys. Geol. Dept.*, ix, 1908, 91–2.

The analysis of bababudanite by Herdsman, except for a slight excess in magnesia, agrees fairly well with the formula

$$4NaFe'''(SiO_3)_2.2FeSiO_3.3MgSiO_3.$$

The mineral differs from riebeckite in containing a high percentage of magnesia, and from glaucophane in its low alumina content. It resembles the analysis of crocidolite from Dochfour (A in Table I) fairly closely, but differs from this mineral in optical properties. The nearest approximation in both chemical composition and optical characters is to rhodusite. According to Isküll[1] the composition of rhodusite may be expressed as an isomorphous mixture of two molecules, namely

---

[1] *Zeits. Kryst. Min.*, 44, 1908, 370–389.

$$Na_2Fe_2Si_4O_{12}, 5(Mg,Fe,H_2,Ca,Mn)SiO_3.$$

The analysis which the writer has given above for bababudanite, if written in similar form would become

$$2Na_2Fe_2Si_4O_{12}, 5(Mg,Fe,H_2,Ca)SiO_3.$$

(iii) *Optical Properties.*—The optic plane and Z are normal to 010. There is a strong dispersion of X, Y, and optic axes. This dispersion and the intense pleochroic colours exhibited by the mineral make accurate measurements very difficult.

$(-)\ 2V$ = about 60°
$\beta - \alpha$ = ·013 to ·014
$\gamma - \alpha$ = about ·018
$X \wedge c$ = about 3°
X = dark Prussian blue
Y = yellow
Z = deep violet blue

4. The Banded Ferruginous Quartzite.

The banded ferruginous quartzites occurring in the Bababudans, have been considered by the officers of the Mysore Geological Department to have originated by the metamorphism of igneous rocks. They were supposed to have been formed by the gradual alteration of "hornblendic beds which are of the nature of amphibolites"[1] or by the metamorphism of "aphanitic greenstones".[2]

As mentioned earlier, Sampat Iyengar discovered bababudanite in the banded ferruginous quartzites. Cummingtonite was also found in other parts of these hills and this induced him to consider that these quartzites were derived by the alteration of bababudanite and cummingtonite schists.[3] In this view Smeeth also concurred. These amphiboles were believed to be original and they were supposed to break up, under the influence of thermal metamorphism, into oxide of iron and silica, which later crystallized as quartz and magnetite giving rise to the banded quartz-magnetite rocks.

This was the position when, in 1932, the writer examined parts of the Bababudan Hills. This visit resulted in the interesting discovery that the occurrence of bababudanite was confined to narrow zones always at the immediate contact of the intrusive epidiorite dykes. Further, the fresh and glistening acicular crystals of this amphibole were often seen to be disposed right across the bands in the original rock. These observations definitely suggested that bababudanite was a later mineral developed at the intrusive contacts of the epidiorites with the banded quartzites and had nothing to do with the origin of the ironstones.[1]

---

[1] W. F. Smeeth, "General Report of the Work of the Department," *Rec. Mys. Geol. Dept.*, ix, 1908, 21.

[2] H. K. Slater, "Report on the Geological Survey of a portion of the Kadur District," *Rec. Mys. Geol. Dept.*, ix, 1908, 56.

[3] P. Sampat Iyengar, *loc. cit.*, p. 73.

This discovery was of no small significance in the genetic considerations of the Bababudan iron formations, and seemed to warrant a close study of the problem of the origin of these banded ferruginous quartzites from a fresh point of view.[2] Due to absence from India, the writer was unable to re-examine these rocks till the beginning of this year. The suggestion of the contact metamorphic origin of bababudanite was tested in other parts of these ranges, and was confirmed beyond any doubt. The banded ferruginous quartzites adjoining the prominent epidiorite dykes of Attigundi, Virupakshikan, and Kemmangandi were seen to be crowded with fresh crystals of bababudanite.

5. BABABUDANITE-MAGNETITE SCHISTS.

In view of the current belief in Mysore that these amphibole schists represent remnants of basic igneous rocks which by alteration have yielded the banded ferruginous quartzites, a specimen of bababudanite-magnetite schist was analysed for me by Mr. W. H. Herdsman. It will be seen from Table II that this analysis bears no resemblance to an igneous rock; on the other hand, the Mysore rock compares very favourably with the amphibole-magnetite rocks occurring as intercalations in the Lake Superior banded ironstones of Michigan and Wisconsin.

It will be seen from the table below that the Mysore rock contains 3·11 per cent of MgO and only a trace of CaO. The dominance of magnesia over lime is characteristic of sedimentary rocks and this is one of the reasons why Van Hise and Leith considered that the Lake Superior iron-bearing formations were chemical precipitates.[3] A similar calcium-magnesium ratio has been observed in the Noamundi area, Singhbum District, India, where also the banded iron ores are supposed to have originated as chemical sediments.[4] The dominance of ferric over ferrous iron noticed in the bababudanite-magnetite schist, when considered in conjunction with the magnesia-lime ratio, strengthens the view that the Mysore rock must have had a sedimentary origin. Another point of difference noticed in Table II is the presence of 2·60 per cent of soda in the analysis of the bababudanite-magnetite schist. The basic rocks adjoining and underlying the banded ferruginous quartzites of the Bababudan Hills are many of them rich in soda, as may be seen from the prevalence of albite and acid oligoclase, and the soda content of the bababudanite-magnetite schist is due to the sediments being derived from these spilitic rocks.[1] The formation of soda amphiboles like bababudanite was thus facilitated near igneous contacts.

---

[1] C. S. Pichamuthu and M. R. Srinivasa Rao, " Amphiboles in the Bababudan Iron Ore Rocks," *Current Science*, i, 1933, 276–7.

[2] M. S. Krishnan, Presidential Address to the Geology Section, *Indian Science Congress, Calcutta*, 1935, 28–9.

[3] Van Hise and Leith, " The Geology of the Lake Superior Region," *Mon. U.S. Geol. Surv.*, lii, 1911, 506.

[4] F. G. Percival, " The Iron Ores of Noamundi," *Trans. Min. Geol. Inst. India*, xxvi, 1931, 200.

6. SUMMARY.

In the year 1907, a soda-amphibole was discovered by Sampat Iyengar in the banded ferruginous quartzites of the Bababudan Hills, Mysore State. Smeeth considered it a variety of riebeckite and gave it the name *bababudanite.* This paper contains a fuller account of the physical, chemical, and optical properties of this mineral. The new analysis published by the writer gives the composition of the mineral as

TABLE II.

	I	A	B	C	D
SiO_2 .	44·15	39·17	42·90	33·89	46·25
Al_2O_3 .	0·25	1·14	—	1·15	0·92
Fe_2O_3 .	40·20	40·42	34·77	49·43	30·62
FeO .	7·98	12·33	15·82	8·46	16·92
MgO .	3·11	1·90	2·62	2·40	2·13
CaO .	tr	1·37	1·33	3·16	1·69
Na_2O .	2·60	—	—	—	—
K_2O .	tr	—	—	—	—
H_2O + .	0·05	2·56	0·47	1·50	0·42
H_2O − .	1·60				
TiO_2 .	tr	—	—	—	—
P_2O_5 .	tr	tr	tr	—	0·07
MnO .	—	0·55	1·73	0·34	1·01
CO_2 .	—	—	—	—	—
	99·94	99·44	99·64	100·33	100·03

I. Bababudanite-magnetite schist. Bababudan Hills, Mysore. Analyst, W. H. Herdsman.

A, B, C. Magnetitic slates. Wisconsin. Irving and Van Hise, "The Penokee Iron-bearing Series of Michigan and Wisconsin," *Mon. U.S. Geol. Surv.*, xix, 1892, 197.

D. Grünerite-magnetite schist. Michigan. Analyst, H. M. Stokes. Van Hise, Bayley, and Smyth, "The Marquette Iron-bearing District of Michigan." *Ibid.*, xxviii, 1897, 338.

$$4NaFe'''(SiO_3)_2.2FeSiO_3.3MgSiO_3$$
$$\text{or } 2Na_2Fe_2Si_4O_{12}.5(Mg,Fe,H_2,Ca)SiO_3.$$

In chemical and optical properties the mineral is allied to rhodusite.

Bababudanite has so far been considered in Mysore to be an original mineral of basic igneous rocks, which by its decomposition due to thermal metamorphism has yielded the iron and silica constituting the banded ferruginous quartzites. As the result of field and laboratory investigation, the writer has come to the conclusion that these amphiboles are secondary minerals formed in the quartzites near igneous contacts, and have nothing to do with the origin of the ironstones. In support of this view, an analysis of bababudanite-magnetite schist is published which agrees well with the analyses of amphibole-magnetite rocks occurring as intercalations in the Lake Superior banded ironstones which are believed to have originated as chemical precipitates.

---

[1] C. S. Pichamuthu, "The Banded Ferruginous Quartzites of the Bababudan Hills, Mysore State," *Current Science*, iii, 1935, 606–8.

7. Acknowledgments.

The writer is very greatly indebted to Professor M. Gysin, Professor of Mineralogy and Petrography in the University of Geneva, for kindly determining the optic axial angle and birefringence of bababudanite. Thanks are due to Dr. G. W. Tyrrell and Mr. B. H. Barrett for help and suggestions during the course of this work in the geological laboratory of the University of Glasgow.

REVIEW.

British Regional Geology: South-West England. By Henry Dewey. pp. vii + 75, with 12 plates and 20 text-figures. *Mem. Geol. Survey*, 1935. Price 1*s.* 6*d.*

THIS publication deals with the geology of Cornwall, Devon, and part of Somerset. Taking into account the vast number of points of interest there presented, it can only be described as a miracle of successful compression. Not only are nearly all the "solid" geological systems represented, the chief exceptions being the Cambrian and the Jurassic, but the phenomena of igneous activity and metamorphism are of special importance, while the superficial deposits present some points of unusual interest. It was no light task to give an intelligible account of all this in 70 pages, but it has been done in an admirable manner. The illustrations also, as plates, set an unusually high standard even for Geological Survey photographs, while their reproduction leaves nothing to be desired.

This region enjoys the special distinction of having been the first systematically dealt with by the infant Geological Survey a hundred years ago, under Sir Henry de la Beche, and may thus be regarded as the birthplace of official geological surveying. It is perhaps noteworthy that the first attempts should have been made on so difficult an area, but the work, apart from questions of nomenclature, has stood the test of time. Furthermore, it seems clear that serious and efficient tin-production went on in Cornwall nearly four thousand years ago.

With so much inviting comment, it is extremely difficult to know where to begin. The present reviewer has always felt a very special affection for the rocks of the Lizard, founded largely on reminiscences of a particularly happy time spent there with Professor Bonney, then over 80 years of age: the ascent of a cliff near Kynance Cove on that occasion was probably the last "scramble" of that famous climber.

For those geologists specially concerned with mining, the problem of the *killas* of West Cornwall has always been of particular interest. Unfortunately it is still somewhat obscure; even in the light of the recent work of Sir John Flett the position cannot be regarded as satisfactory: perhaps the problem will always remain insoluble, owing to the intensity of the dynamic metamorphism, which tends to reduce all rocks to a common denominator by obliteration of distinctive features: almost anything except a pure quartzite or limestone can be converted into a kind of greasy-looking sheared slate or phyllite, which is what much of the Killas consists of, away from the granites.

It is notable that Mr. Dewey is quite definite in his ascription of kaolinization to a late phase of pneumatolysis; with this probably every one who is really acquainted with the subject in Cornwall will agree. Nevertheless it is an undoubted fact that in tropical countries a very similar type of alteration of granites is produced to a surprising depth, a hundred feet or more, by chemical weathering. These two statements are in no wise contradictory, but complementary, and much argument might have been saved if this had been recognized earlier. The relation of china-clay deposits in the St. Austell district to the trend of mineralized veins is quite conclusive of a pneumatolytic origin—and the principal agent of alteration seems to have been carbon dioxide, which is wholly consistent with the phenomena seen in tropical weathering.

Unfortunately space will not allow of a discussion of many of the interesting geological problems relating to the later episodes of geology in this district, but one further remark may perhaps be allowed: he would be a bold man who would venture to draw a definite line between the Permian and Trias in Devonshire, which is but another argument for the revival for general use of the good old term "New Red Sandstone" for the post-Carboniferous and pre-Jurassic rocks of Britain, with transfer of the Rhaetic to the Jurassic, as the beginning of the great Mesozoic marine transgression.

R. H. R.

CORRESPONDENCE.

SPIRAL CONCRETIONS AND BORING ORGANISMS.

Sir,—The writer was interested to read the recent paper by Mr. Thomas on " spiral concretions " (*Proc. Geol. Assoc.*, xlvi, 1–17, 1935). Mr. Thomas's conclusions as to the origin of these structures seem, however, at variance with certain facts put forward by the writer some few years ago (*Proc. Nat. Acad. Sci.*, 19, 139–143, 1933).

At one locality in the Miocene of Maryland there is exposed a sharp change of lithology between sands above, and fine-grained, " brittle " clay below. The contact between these two types is shown to be unconformable by its rising against the regional dip, by boring and channelling of the upper surface of the clay, and by consideration of distribution and other stratigraphic data.

Extending downward for a distance of some 2 feet from the top of the clay are spiral " structures ". They resemble exactly holes which might be made by a corkscrew 2 feet long and 1½ inches outside diameter—these holes then being filled with sand from the bed overlying the unconformity. The " filling " of the holes is identified by its different colour, as well as by its mechanical and mineralogic composition.

At least two possible origins of these structures suggest themselves: (1) spiral concretions were formed in some manner in the clay; then these concretions were carried entirely away, sand from the overlying bed being substituted for the material of the concretions, or (2) animals (or plants ?) living on the surface of the clay made spiral borings in it, during, or probably after which time, sand filled the borings. The sand continued to accumulate, forming the overlying bed.

To (1) it may be objected that: there are now no concretions, nor signs of concretions in the clay, or in the sand above; that the walls of the " borings " are sharp and clean, with no weathering or leaching of any kind visible; that it is remarkable that the putative concretions should all reach upward just to the unconformity at the top of the clay; that there are no joints, bedding planes, or other obvious channels for solutions to pass through the apparently impermeable clay; that, finally, *had* there been spiral concretions present, *their* origin would remain totally unexplained, despite references by Thomas to experiments on diffusion into gels and like substances. Lange has described " spirale Wohngänge " consisting of one spiral within the other (*Zeits. d. d. Geol. Ges.*, 84, 537–543, 1932). Diffusion into a gel would seem to be even less likely as an explanation in this case.

To (2) it may be objected that the boring form is not known.

It seems to the writer that no explanation other than that of boring from above is applicable in the cases described. However, one can easily envisage induration of the sand fillings, and their subsequent separation from the less resistant rock surrounding them by erosion, weathering, or other processes. One confronted by such isolated structures might make almost any guess as to their origin. The examples figured by Thomas, as well as those of Mansfield, seem to be such indurated fillings, which now have lost most of their meaning because nothing is known of their relation to the rock which invested them.

LINCOLN DRYDEN.

BRYN MAWR COLLEGE,
BRYN MAWR, PA., U.S.A.

ANNOUNCEMENTS.

CLOUGH MEMORIAL RESEARCH FUND.

Through the generosity of Mrs. Clough a fund was instituted in 1935 in memory of her late husband Dr. C. T. Clough. The purpose was to encourage geological research in Scotland and the North of England, where Dr. Clough carried out his outstanding work. The North of England is defined as comprising the counties of Northumberland, Cumberland, Westmorland, Durham, and Yorkshire. Under the terms of administration of the fund a sum of approximately £30 will be available annually.

Applications for the grant are invited for the period 1st April, 1936, to 31st March, 1937. These applications should state:

(1) The nature or research to be undertaken.

(2) The amount of grant desired.

(3) The specific purpose for which the grant will be used, e.g. travelling expenses, maintenance in the field, excavations of critical sections, etc.

(4) Whether any other grant in aid has been obtained or applied for.

Applications should be in the hands of the Secretary, Clough Memorial Research Fund, Edinburgh Geological Society, Synod Hall, Castle Terrace, Edinburgh, not later than 1st February, 1936.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIII.

No. II.—FEBRUARY, 1936.

ORIGINAL ARTICLES.

Reverse and Oscillatory Zoning in Plagioclase Felspars.

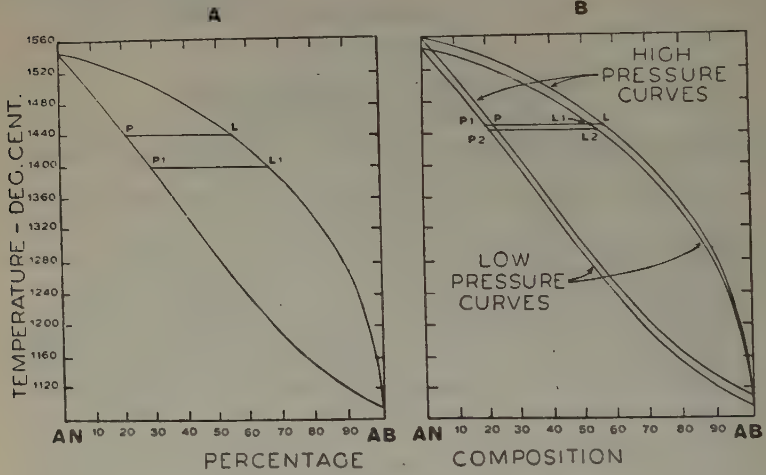
By Edwin Sherbon Hills, University of Melbourne, Victoria, Australia.

THE importance of accurate knowledge concerning the causes of composition zoning in plagioclases lies in the possibility that such zoning may throw light on the magmatic history of the rock of which the zoned felspar is a component. The interpretation of plagioclase zoning has been the subject of much speculation among petrologists, Phemister having recently contributed (1934) a valuable discussion of earlier work, together with certain new suggestions as to the probable causes of the reverse and oscillatory types. My own attention was drawn to oscillatory zoning while studying the Upper Devonian igneous complex of Marysville, Victoria (Hills, 1932, pp. 152, 153), and I found the hypotheses suggested by Phemister and by Harloff (1927) to explain this enlightening. Nevertheless, it seems to me that the real significance of some of the processes postulated by both these workers has not been correctly indicated, and that the mechanism proposed by Phemister to account for oscillatory-normal zoning is not theoretically possible. Since it is important that the physico-chemical basis of such hypotheses be sound, a discussion of Phemister's and Harloff's theories, and certain other possible causes of reverse zoning is given below.

Oscillatory-Normal Zoning.

Phemister's Theory. (*Diffusion-Reaction Control.*)—The stages postulated by Phemister to account for oscillatory-normal zoning, in which, while An-rich zones repeatedly recur, there is a general outward tendency towards more Ab-rich plagioclase, are as follows:—"(i) Deposition of plagioclase with a much higher An : Ab ratio than in the magma, and concomitant concentration of albite in the liquor within the domain of crystallization; (ii) reaction of the crystal periphery with the more albitic liquor to form a less calcic plagioclase, and concurrent rise of the An : Ab ratio in the liquor both through reaction and through diffusion ; (iii) deposition of calcic plagioclase once more." As the magma cools, both the more and the less calcic zones will progress towards more sodic compositions.

During the crystallization of plagioclase felspars of the Ab : An series, stage (i) above is normal, the composition of the crystal phase in equilibrium with a liquid of known composition being determinable from the phase diagram (Text-fig. 1 A).



TEXT-FIG. 1.

Regarding stage (ii), Phemister says : " Indeed it would seem likely that temperature change within the domain of crystallization should, owing to release of heat on crystallization, be in the direction of a slight rise. If, therefore, the rate of diffusion is considerably less rapid than the rate of crystallization, deposition should cease, and there is a possibility that resorption may ensue or that the crystal margin may be changed over into less calcic felspar by reaction with the surrounding more albitic liquor."

I suggest that this argument is fallacious, because (*a*) if the temperature remains constant and does not show a slight rise, the crystal phase will remain in equilibrium with the liquid from which it crystallized, and no further reaction will take place ; (*b*) there is no possibility of the temperature rising as a result of crystallization, since, as soon as the heat given off on crystallization equals the heat lost by the magma, crystallization will cease ; (*c*) assuming that a slight rise could take place, say, from external causes, plagioclase of higher, not lower An : Ab ratio, would tend to develop by reaction with the liquid. It is with falling temperatures only that the reaction postulated by Phemister at stage (ii) can proceed, and in this case any later crystallization of more calcic plagioclase must take place from a supersaturated liquid, which Phemister believes can be developed only once during the magmatic history. This will be further considered below.

Harloff's Theory (*Diffusion Control*).—According to this theory, which is rejected by Phemister, the slow diffusion of felspar molecules towards the growing crystal results in the precipitation of a more albitic felspar than would have resulted if diffusion had kept the composition of the liquid phase uniform throughout.

Later a more An-rich zone is deposited when diffusion brings more An molecules into the liquid in contact with the growing crystal interface. Phemister rejects this hypothesis because he regards large temperature variations as necessary to account for the deposition of the alternately An and Ab-rich zones using Harloff's theory, but I do not think that his own hypothesis avoids this difficulty, which can only be surmounted if it be admitted that equilibrium conditions are not constantly maintained during crystallization, and if, in particular, the possibility of recurrent supersaturation of the liquid phase be allowed.

Possible Supersaturation Effects in Magmas. — The usual experiments demonstrating the effects of supersaturation in chemical laboratories have little value as analogues with the condition in magmas, for the ionic mobility in magmas is in all probability much less, with the exception of pegmatites, than is the case in the salts used in such experiments. The great difficulty of crystallizing many plagioclase melts is well known. Furthermore, in laboratory experiments on supersaturation, fusions or concentrated solutions of pure salts are used, so that the result of crystallization is a practically solid and continuous mass of crystals. If, however, in a plagioclase melt the degree of undercooling is only sufficient to cause the liquid to enter the field between the liquidus and solidus curves, and not to pass beneath the solidus curve, then on attainment of equilibrium with crystallization the whole melt does not become crystalline. This applies with even greater force to a polycomponent system such as a magma, where plagioclase forms only a part of the liquid phase. The result of crystallization from such a system is that a dispersed crystal phase is developed in the liquid, and the possibility now exists, which does not exist in the case of an undercooled melt of a pure substance, that the liquid should again become undercooled and supersaturated. This will occur (*a*) if the crystal phase is so widely dispersed that the domains of crystallization around the crystals do not overlap, and (*b*) if the crystals should fail to act satisfactorily as inoculating agents. In magmas, the first possibility may arise through the sinking of crystals, which results in a concentration of phenocrysts downwards and a reduction in number with consequent wide dispersal upwards, and the second possibility is suggested by the experiments of Day and Allen (1905), who found that the inoculation of an undercooled albite melt with finely ground crystals did not induce crystallization in the melt.

In an experiment described by Harloff, where the crystallization of NaCl for aqueous solution was observed under the microscope, the growth of the crystals was found to be intermittent. Crystallization halted at intervals in the case of each individual crystal, until apparently diffusion had supplied more atoms for crystal growth. This implies a small degree of local recurrent supersaturation, even with mobile ions. The effect cannot be due to release of heat from the growing crystal, since it is a necessary condition for crystallization that the rise of temperature due to latent heat released shall be less than the fall in temperature due to external causes. At any instant, those parts of the liquid which will next supply $Na^{\cdot}$ and Cl' ions to the crystals which have momentarily ceased growth, must be supersaturated.

It is, therefore, not improbable that recurrent local supersaturation should occur in magmas during crystallization.

Diffusion-Supersaturation Theory.—With this in mind I would suggest the following mechanism[1] for the production of oscillatory normal zoning in plagioclases: (i) crystallization of plagioclase, P (Text-fig. 1) in equilibrium with liquid L; (ii) continuation of crystallization with falling temperature, the liquid close to the crystal interface changing from L to L1, and the crystal from P to P1, the slow diffusion of felspar molecules towards the growing crystal resulting in those parts of the liquid further away from the crystal remaining richer in An than L1, but in a state of supersaturation; (iii) diffusion of more An molecules from these supersaturated parts, especially during any slower periods of cooling, towards the crystal, resulting in the deposition of an An-rich zone; (iv) repetition of these processes with the outer zones becoming progressively more Ab-rich.

This theory accounts for the observed fact that oscillatory-normal zoning is fairly common in phenocrysts, and very rare in groundmass felspars, for, as has been shown, supersaturation is more likely to occur with widespaced crystals than with close packing, and repeated zoning implies a long crystallization history such as, presumably, phenocrysts have endured.

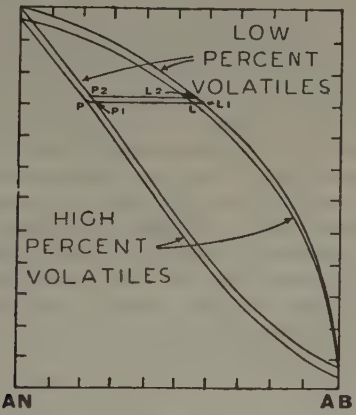
To explain the deposition of major zones which are more basic than the first formed plagioclase, it would be necessary on this hypothesis to postulate a degree of supersaturation of a much greater magnitude than need be assumed to account for most cases of oscillatory zoning, and I think it is more probable that reverse and oscillatory-reverse zoning are due to other causes.

---

[1] The binary system An : Ab is used in this paper to illustrate the theories discussed because of the ease with which it can be interpreted. In poly-component systems such as magmas, while the general principles established for the binary system no doubt remain valid, quantitatively the effects must be different.

REVERSE AND OSCILLATORY-REVERSE ZONING.

Escape of Volatiles.—Fenner (1926) suggested that the escape of volatiles from the crystallizing magma might be a possible cause of simple reverse zoning (deposition of zones progressively more An-rich). Phemister rejected this explanation, but neither he nor Fenner gave reasons for maintaining these diametrically opposed views.



TEXT-FIG. 2.

I believe that Phemister's view is the correct one, for, if the addition of volatiles may be treated as having the effect of lowering the normal cooling curves for the Ab : An series, as in Text-fig. 2, then it follows that, with a high percentage of volatiles, plagioclase P would crystallize from liquid L. Loss of volatiles at this stage might cause the equilibrium relations to be represented by the upper curves, so that plagioclase P is stable, but liquid L is unstable. Plagioclase P1 and liquid L1 will tend to develop, P1 being more albitic than P, so that under suitable conditions plagioclase P will be bordered by a sharply bounded outer zone of more albitic composition. A slight rise of temperature should result from the crystallization of the unstable liquid L, and the conditions might be represented by liquid L changing to liquid L2 in equilibrium with plagioclase P2, more albitic than P. Thus it appears probable that loss of volatiles would cause normal rather than reverse zoning.

The sinking of crystals from higher to lower levels in the magma chamber, as suggested by Bowen (1929), may result in reverse zoning, in which case one might expect to find some evidence that the inner, more albitic core was at one time heated above its melting point.

Effect of other Mineral Components.—Another suggestion that has been made by Bowen (1913), but which is not discussed by Phemister, is that " the secret of reversal may at times be found in the presence of other lime-bearing minerals in the natural rock". Bowen does not refer to this in any of his later works, but Väyrynen (1923) has put forward a similar suggestion with fuller discussion. He considers that the precipitation of diopside uses up so many Ca″ ions that the crystallization of plagioclase results, which is more Ab-rich than "aus der Zusammensetzung des Gesteins folgen würde". Later resorption of the diopside and crystallization of An-rich plagioclase follows because of the piling up of Al_2O_3 in the magma residuum. Furthermore, when biotite begins to crystallize, Al_2O_3 is again used up, crystallization of diopside and Ab-rich plagioclase beginning again. This, once more, results in piling up of Al_2O_3 in the magma residuum, and the consequent later resorption of diopside and crystallization of hornblende and An-rich plagioclase. I can see no grounds for believing that such variations in the composition of the plagioclase crystallizing from a polycomponent system should occur, since this would involve the postulate that plagioclase of the same composition should be stable at a number of successively lower temperatures, and the diopside-plagioclase phase diagram, at least, shows no effects such as this. In any case, it is improbable that the outward gradation of the major zones would be towards a final, more basic plagioclase than that first formed, which is the condition Väyrynen is attempting to explain.

Pressure Effects.—There remains for consideration the effect of variations of pressure on the crystallizing magma, through some external cause. Phemister points out that relief of pressure on the magma may cause an advance of hot magma from below, and says: "It is by periodic accession of such hot magma that the writer would explain the abrupt recurrence of the more calcic zones which form the inner shells of the main zones of oscillatory-zoned crystals, the abrupt appearance of highly calcic shells, and the phenomenon of outer zones more calcic than the core." This hot magma is irrupted into the crystallizing liquid, apparently—although this is not expressly stated—intimately mingling with it and precipitating calcic plagioclase around the crystals already present. This theory involves the assumptions (*a*) that the early formed crystals, although raised to the temperature at which calcic plagioclase will precipitate, do not change their composition in accordance with the phase diagram either by reaction with the liquid or by the production of small amounts of a new liquid phase; and (*b*) that the mixing of the two magmas is very intimate. Admitting that the first postulate may not be improbable, there are difficulties in accepting the second, which is somewhat similar to the theory of Herz (1892), who believed that zoning in plagioclase is due to currents which bring the crystals into contact with parts of the magma where plagioclase has not yet crystallized. This was rejected by Becke as improbable, for the mixing of two magmas or parts of a magma, unless occurring near a vent where violent agitation may take place, will be limited by the generation of flow lines, the different magmas remaining intact within each minor current. Nevertheless, considering the variety of conditions that can exist in nature, one feels that Phemister's theory may well explain the phenomena in question, which are not the usual condition, but the unusual, and which certainly necessitate the introduction of some radically discontinuous factor into the crystallization history of the felspar.

Finally, there is the possibility that changes in the pressure acting on the crystallizing magma may result in zoning, if equilibrium conditions are not constantly maintained, because of the direct effect of pressure alterations on melting points. The phase diagram for the Ab-An system shown in Text-fig. 1 represents the relations between liquid and solid at a given pressure, in this case, atmospheric pressure. With increased pressures, however, the melting points of the felspars will be raised, that is, the liquidus and solidus curves will be displaced upwards. I cannot find any figures relating to the effect of pressure in raising the melting points of the plagioclases, but Rastall (1927, p. 23) states that in the case of most minerals it amounts to 0·09° C. per atmosphere. This is probably a maximum figure, but if it should hold for the plagioclases, a release of pressure equivalent to the weight of a column of rock 2,000 feet thick would result in a reduction of the melting point of about 15° C. (see Harker, 1909, p. 163). In Text-fig. 1 B, if plagioclase P is in equilibrium with liquid L at high pressure, and a sudden reduction of pressure of the above amount occurs, this plagioclase and liquid will no longer be in equilibrium, for the lower set of liquidus and solidus curves represent the stable conditions. Felspar P is now superheated, and will tend to alter its composition to P1 by reacting with the liquid phase to produce liquid L1. If equilibrium conditions were not maintained, felspar P1 might be produced as a border around felspar P, which would become stable with falling temperature, and even if a slight general lowering of temperature should accompany the reduction of pressure, so that P would change to P2 and L to L2, the outer zones of the plagioclase crystals would still be more basic than the inner. In this way a reversal of zoning might result, with a difference between adjacent zones of about 10–15 per cent An. It is perhaps conceivable that sudden releases of pressure of the amount necessary to produce an effect such as this might occur in the case of magma rising along fractures, and smaller pressure reductions, such as might occur during the uprise of magma chambers, might be the cause of oscillatory zoning where the differences in composition are not very marked.

I find it difficult to decide whether the deposition of more calcic zones owing to pressure release would be conformable or unconformable on the core of the crystal, as so much depends on the suddenness of the release and the properties of superheated crystalline felspar. In consideration of the fact that superheated felspars in the magma would be bathed in liquid, I think it is probable that, in most cases, signs of reaction would be observable around the core.

The figures given above are so uncertain as to have little value, but they do serve to illustrate another possible method by which reverse and oscillatory zoning might be produced. In conclusion I desire to thank Dr. H. S. Summers for a critical perusal of the manuscript of this paper, which may at least have served to indicate the complexity of a subject already reduced to an orderly and rational condition by the work of Dr. Phemister.

BIBLIOGRAPHY.

Bowen, N. L. 1913. "The Melting Phenomena of the Plagioclase Feldspars," *Amer. Journ. Sci.*, **4**, xxxv, 577–599.

—— 1929. *The Evolution of the Igneous Rocks*, Princeton Univ. Press.

Day, A. L., and Allen, E. T. 1905. "The Isomorphism and Thermal Properties of the Feldspars," *Carnegie Inst., Washington, Pub. No.* 31.

Harker, A. 1909. *The Natural History of Igneous Rocks*, Methuen and Co., London.

Harloff, C. 1927. "Zonal Structure in Plagioclases," *Leid. Geol. Med.*, ii, 99–114.

Herz, R. 1892. "Ueber die Zonarstruktur der Plagioclase," *T.M.P.M.*, xiii (n.f.), 343–8.

Phemister, J. 1934. "Zoning in Plagioclase Felspar," *Min. Mag.*, xxiii, 541–555.

Rastall, R. H. 1927. *Physico-Chemical Geology*, Edward Arnold and Co., London.

Väyrynen, H. 1923. "Petrographische Untersuchungen der Granito-dioritischen Gesteine Süd-ostbothniens," *Bull. Comm. Géol. Finlande*, No. 57.

The Tectonics of the Purbeck and Ridgeway Faults in Dorset.

By W. J. Arkell, University Museum, Oxford.

1. Introduction.
2. The Purbeck Fold and Fault.
    - (*a*) Swanage.
    - (*b*) Lulworth.
    - (*c*) General considerations.
3. The Relations of the Tertiary to Older Movements.
4. The Ringstead, Chaldon, and Other Subsidiary Folds on the Foreland.
5. The Ridgeway Fault.
    - (*a*) General.
    - (*b*) Previous interpretations.
    - (*c*) Observations on the effects of the fault on the rocks in contact with it, its relations to folds, and its hade.
    - (*d*) The question of the continuity of the fault.
    - (*e*) The Bincombe and Ridgeway Inliers.
    - (*f*) Some analogues.
6. Summary of Conclusions.
7. References.

1. Introduction.

It is now about forty years since the completion of the late Sir Aubrey Strahan's *Geological Survey Memoir on the Isle of Purbeck and Weymouth*, published in 1898. All those who, like the present writer, have known the Dorset coast from boyhood and have carried Strahan's maps and memoir over most of the ground many times cannot have failed to learn from them lessons of incalculable value. They will have come to regard the memoir as a model of scientific method and of lucid presentation, a classic not to be questioned save in matters of palaeontology, now necessarily out of date.

Of all the chapters the most interesting and, for its time, most brilliant, is number xv, "Disturbances and Faults," in which Strahan elaborated a paper published in 1895, tracing, describing and interpreting the complicated folds and faults, and distinguishing those of Intra-Cretaceous from those of Tertiary age. The memoir of 1898 alone need be referred to here, since it sets forth the gist of the earlier paper with greater detail. The same ideas were summarized in 1906 in the well-known *Guide to the Geological Model of the Isle of Purbeck*, which appeared in a second edition in 1932. As a result of these publications, Strahan's interpretation of the Purbeck and Ridgeway Faults has been accepted for forty years and copied by writers of textbooks and taught to generations of students.

It is this central theme of Strahan's work, however, that it is now proposed, with all due deference, to examine critically. The attempt is not made without a knowledge of the ground which, although acquired by the help of Strahan's writings, probably extends over a longer period of time than Strahan himself was able to devote to the subject.

2. The Purbeck Fold and Fault.

It is hardly necessary to recall that Strahan interpreted the Isle of Purbeck fault as an overthrust from north to south, and that by analogy with the Purbeck overthrust he then interpreted the Ridgeway fault, and the complicated structures revealed by the Bincombe railway-cutting, in the same way. Those who wish to follow the argument in this paper should have by them Strahan's memoir, and especially pp. 214–229, chapter xv.

This chapter, which at first reading appears such a masterly piece of exposition and inference, is found on closer examination to contain some serious errors of reasoning; so serious that they invalidate the whole superstructure built upon them.

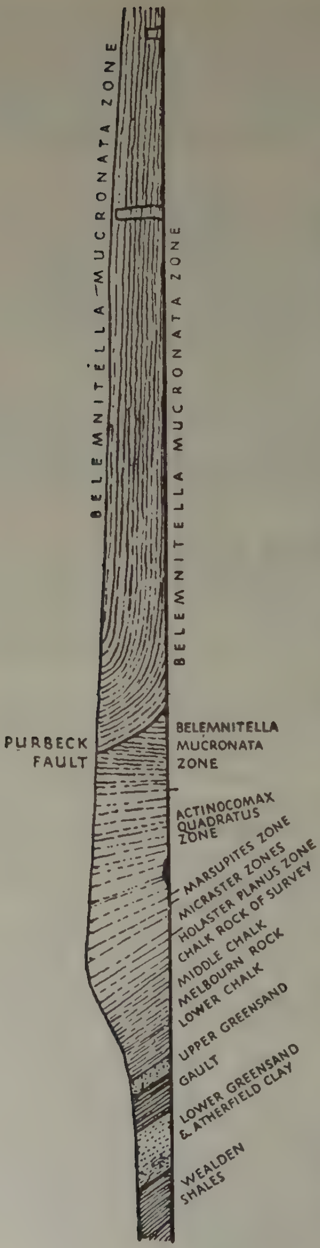
(a) *Swanage.*

Strahan describes the disturbances in geographical order from east to west. He begins with the renowned section across the Isle of Purbeck fault at Ballard Point, Swanage,[1] from an inspection of which, he states, "we may ascertain the following facts:—

"1. The strata above it [the fault-plane] are bent into a curve,

---

[1] The best published photograph is in Rowe, 1901, pl. viii, with zonal explanation. See Text-fig. 1 herewith.



TEXT-FIG. 1.—Section across the Purbeck Fault at Ballard Point. Outline and dip of beds after Strahan (1898, pl. xi), the Chalk zones added after Rowe (1931, p. 32). Length of section about ¼ mile. True scale.

obviously forming part of the monoclinal structure which was the first stage in the disturbance.

"2. The fracture follows the bedding of the strata above it, but cuts across the bedding of those below.

"3. The strata above the fracture have been pushed southwards relatively to those below, and then over them" (1898, p. 216).

The beginning of the next paragraph states that "these observations" lead to three inferences.

Now the second part of 1, above (following the word "obviously"), and 3, are not facts or observations, but already inferences, if not pure assumptions. No. 3 is, in fact, what Strahan is setting out to prove. But he seems to have been so obsessed by the idea of a north-to-south overthrust, which was first suggested by Conybeare (1822, p. 111) in every detail save the actual use of the word overthrust, that he forgot to prove it, and eventually came to regard it as an observation and a fact.

The actual observations or facts that we are justified in setting down as the result of an inspection of the Ballard Point section appear to me to be limited to the following :—

1. The strata below the fracture stand vertical, while those above it are gently inclined in the form of an arc of a circle, and spread out to run almost horizontally a short distance north of the visible part of the fault. Near the junction with the Tertiary there is a second and gentler plunge down northwards.
2. The fracture follows the bedding of the strata above it, but cuts across the bedding of those below.
3. Towards the south the chalk below the fracture is older than that above it, whereas towards the north it is younger ; but the differences in age are very slight, for the fault-plane lies wholly in the zone of *Belemnitella mucronata* (Rowe, 1901, pp. 32, 36).

From these data we have to determine in what direction the movement took place. Strahan infers "that that part of the chalk in which the fracture followed the bedding has been pushed bodily over that part in which it cut across the vertical bedding". We here find stated as an inference precisely what, in different words, was presented in the preceding paragraph as an "ascertained fact" or "observation" (cf. Strahan's third fact and third inference, p. 216). No proof or argument whatever is offered.

If the north to south overthrust hypothesis (as I think I have now justified myself in calling it) needs no proof, it should at least be mechanically workable. Strahan's own section shows that it is not (No. 1 on his plate vii, facing p. 228).

It is the essence of the hypothesis that the upturning of the chalk above the fault-plane is "part of the original monoclinal structure which was the first stage in the disturbance" (Strahan's first "fact" on p. 216, quoted above). The upthrust strata, on his view, "must have" (1906–32, p. 9) formed part of the lower curve of the reversed "S" constituting the original monocline. As Strahan's own reconstruction shows, however, it is impossible to bring this lower curve of the reversed "S" into its present position by means of a southward thrust. The thrust would first have to grab the curved strata out northwards from their position below the vertical portion of the curve exposed in the cliff, and then push them back southwards again at a higher level. In other words, the thrust would have to be preceded by a normal fault down-throwing south in order to bring the curved strata northwards in readiness to be thrust southwards. No such double movement was visualized by Strahan and there is no evidence for it. He shows the lower curve of the reversed "S" by means of dotted lines *still in position* below the vertical strata below the fault plane! The same strata have to be in two places at once! But his section also shows that at the point from which he visualized the curved strata as being derived (i.e. under sea-level about 400 feet to the north of the visible portion of the fault) the strata are not curved but horizontal and straight. As he states in his text, "On inspection of the section it will be seen that the vertical strata below the fault must curve round at no great depth below the sea, until they become parallel to the fault and eventually run into it, thus completing the monoclinal structure; and, further, it may be presumed that the curving strata above the fault were brought up from the point where that parallelism takes place."

Hence, aside from the question as to whether the fault is normal or reversed, we seem justified in drawing the following inferences. The first, it will be noted, is a flat contradiction of Strahan's first inference, which he thought so "obvious" that he called it an ascertained fact.

1. The curve in the strata above the fault-plane cannot be part of the monoclinal flexure.

2. The curve in the strata above the fault-plane was therefore probably produced later, as a result of the second movement, the faulting, rather than the first movement, the flexuring. (Since the vertical strata of the monocline are cut by the fault, the faulting must post-date the original flexuring.)

The second inference follows almost as inevitably from a different consideration. Strahan's idea that the curved strata formed part of the original monocline and were thrust up with their curve intact involves the assumption that the curved strata not only retained their form during the thrusting but forced the thrust-plane to take exactly the shape that would accommodate them. This is inconceivable. It is more likely that the curvature was imposed upon the faulted strata as an adaptation to a curved fault-plane, upon which they rode and against which they were pressed by the weight of a superincumbent load of rock since removed by erosion; namely, that it was a form of drag.

If, then, the downward-convex curve in the strata above the fault-plane is not the lower curve of the monocline, it follows that there is no more reason for supposing that the strata so curved were brought up from below than for supposing that they were lowered from above. Strahan supplies no other reason for considering the movement to have been a thrust. Since normal faulting is a simpler process than reversed faulting, the possibility of explaining the structure in question by means of a normal fault should be exhaustively explored first. It seems to me that the structure can be so explained, although Strahan did not attempt to do so.

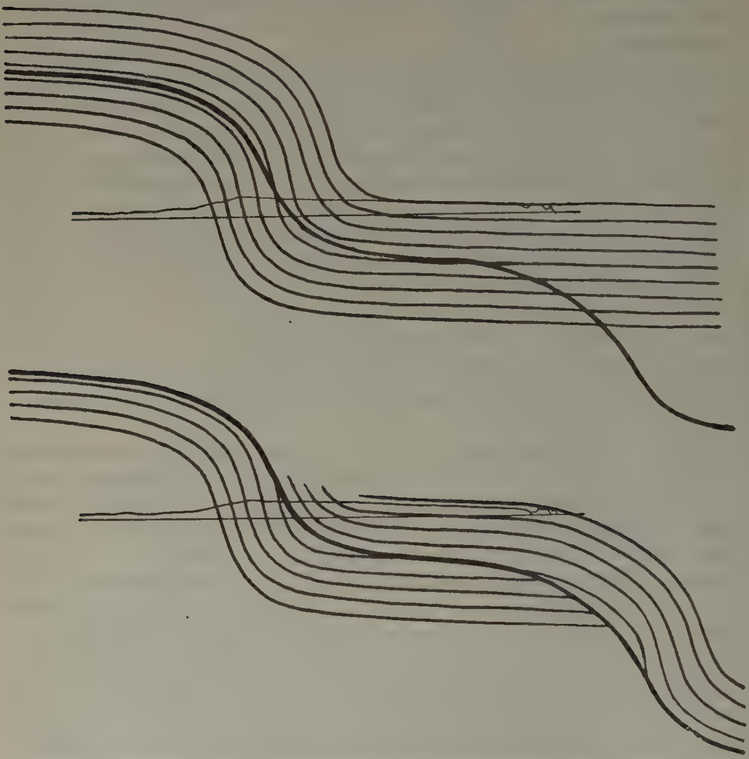
If we reconstruct the monocline as it appeared before the faulting (which we can do from the strata preserved below the fault-plane, and by analogy with the section from Freshwater Bay in the Isle of Wight to the Needles, to a degree of accuracy sufficient for our purpose) and then superimpose it upon Strahan's drawing of the observed section (Text-fig. 2), we can see that it is possible to bring the shifted rocks into their present position by means of a normal fault of rather flat and undulating hade. The continuation of the fault-plane can also be drawn in above and below the small portion actually visible. It will be observed that this process at the same time automatically explains the second and gentler downward plunge of the strata at the base of the Tertiaries at the southern corner of Studland Bay.[1]

It is an illuminating experiment to draw such a diagram and cut the paper along the line of the fault, so that the upper portion can be slid downwards until the arrangement actually visible in the cliff is produced. It will be seen that with a non-plastic substance such as paper, once a concave curve or undulation in the fault-plane like that seen in the cliff is introduced, a series of others have to be provided below to accommodate the bulging strata taken from the one above, as shown in Text-fig. 2 ; otherwise the downthrown strata in the cliff will not be horizontal but will dip southwards into the fault. In practice, however, the powers of chalk under pressure to accommodate itself to the fault-plane bed were probably almost perfect. There is therefore probably no need to postulate such a regular step-like series of undulations. The one actually visible in the cliff is coincident with, and therefore probably caused by, the verticality of the hardest (most compressed) part of the chalk at that point. The adaptability of the chalk to the contours of its bed is demonstrated by the curvature of the visible portion already discussed. Presumably this chalk was originally straight, or even curved the other way, before it slid down off the brow of the monocline into its present position. We may visualize the movement of the chalk across such an undulation in the fault-plane as analogous to that of a train upon a scenic railway. At whatever moment the movement were arrested, the train would be parallel with and at all points contiguous with the rails, however those might be curved. The motion is, in fact, a *flow* like that of a glacier.

---

[1] Strahan's coast-sections stop short at Handfast Point and so do not show this increased dip at the base of the Eocene.

Until any better solution has been offered, therefore, I see no reason for not regarding the Purbeck Fault at Ballard Point as a normal fault, a settlement or adjustment following on the relaxation of the greatest pressure that gave rise to the monocline. How far the faulting was contemporaneous with the later part of the monoclinal elevation it seems impossible to say. It is unlikely



Text-fig. 2.—Diagrams illustrating the suggested explanation of the structure in the Chalk at Ballard Point by normal faulting. Above, the monocline before the faulting, but with the fault-plane drawn in. Below, the same after faulting. The fault-plane is drawn as it would have to be if the chalk below the sea-level were non-plastic. Actually the curve of the strata below sea-level has probably been much flattened out during the movement and the fault-plane below them may be nearly straight. The downthrown block has been tilted slightly towards the fault, which would be one of the results of the fault-plane below sea-level having a shallower concave bend than that seen in the cliff.

that the upcurving of the fault-plane at Ballard Point was due to a continuance or recrudescence of the movements of elevation, the fault-plane having been originally straight, for the curve is too small and too sharp.

(*b*) *Lulworth.*

On the colour-printed Survey Map of 1904 (Sheet 343) the Isle of Purbeck Fault is marked for only 2 miles inland, as far as the cross-fault in the Ulwell valley. A gap of 9 miles then follows before it reappears on the map (Sheet 342) at Whiteway Hill above Tyneham, whence it is labelled "Isle of Purbeck Thrust Fault" and marked as passing just inland of the coast for 5½ miles, until it runs out to sea 500 yards west of Bat's Head, 2½ miles west of Lulworth Cove.

An examination of this section from the beach and from a boat, especially when made in conjunction with a study of the other chalk cliffs west of Lulworth, yields results of the greatest interest. An extensive fall of cliff between 1910 and 1913 at the critical point has rendered the section probably clearer than it was at the time of the Survey about 1890.

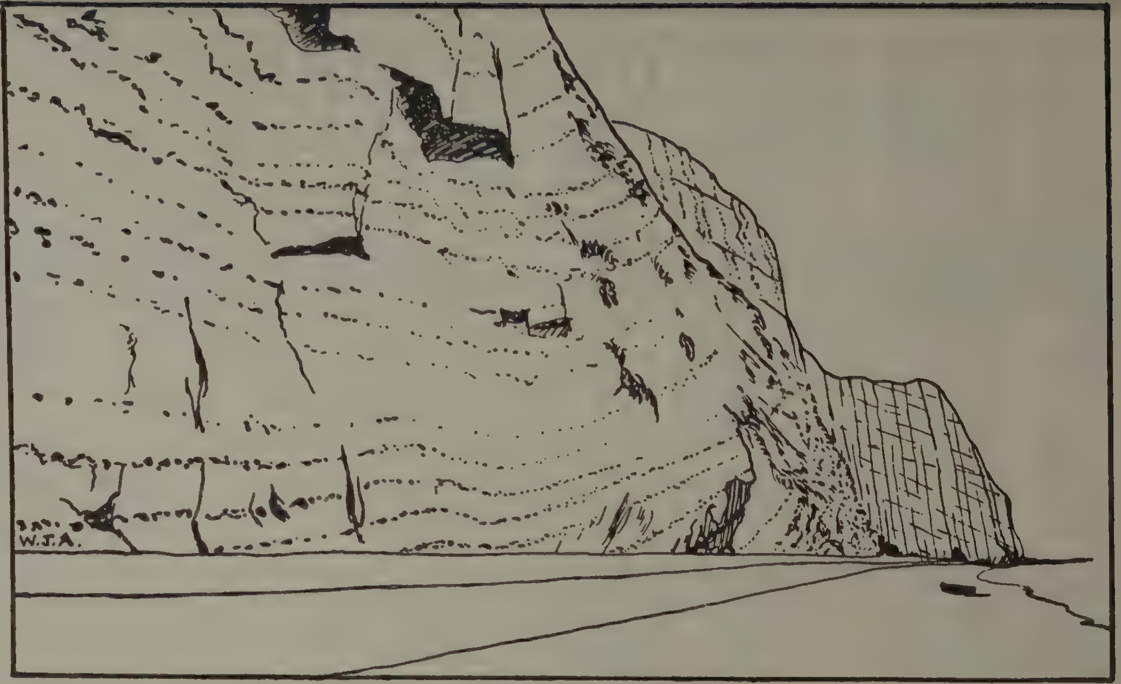
Although the fault is marked as a thrust fault on the map, Strahan makes no mention of thrusting here or in the neighbourhood, except along numerous minor and separate thrust-planes hading gently southwards, along which the movement has been in the opposite direction, *from south to north.* These occur in the vertical chalk all along Man-o'-War and Durdle Coves and in Swyre Head and Bat's Head. The best are easily accessible from the beach in Durdle Cove and a line of caves has been hollowed out by the sea along the largest. "They occur at irregular intervals one above the other, and in every case the roof has moved northwards and upwards over the floor, a distance varying from 4 to 12 feet, and possibly more" (Strahan, p. 219).

Of the interpretation of these structures there can be no question. A particularly instructive view is to be obtained from near Bat's Head, looking eastwards along the face of the cliff of Swyre Head (seen in Text-fig. 4, p. 67). The chalk below the thrust-planes can be seen to be almost perfectly vertical. That above the thrust-planes, being the portion that has been driven northwards, is inverted and pushed out northwards like a sail filled by the wind. The small thrust-planes have clearly given relief to the northward overdrive of the brow of the steepening monocline. The movement along the most important of these slide-planes in Durdle Cove has been determined quantitatively in terms of Chalk zones by Rowe (1901, pp. 15–17, and plates iii, iv). The vertical strata of Bat's Head are cut by scores of diminutive thrust-planes along which the movement has only been a few inches, but always in the same direction.

When we round Bat's Head and walk westward along the beach to White Nothe we soon cross the point where the Purbeck Thrust Fault is supposed to cut the cliff obliquely, as described by Strahan (p. 220 and plate ix). In Bat's Head itself and the little cove to the west, the chalk is still vertical and the section is identical with that in Swyre Head, with numerous gently-dipping thrust-planes and some puckering and inversion above the larger ones. Strahan states that the lowest chalk preserved in Bat's Head is above the Survey's "Chalk Rock," and Rowe (1901, plate i) marks it as *Holaster planus*-zone. Then, as we pass westwards, the chalk at the foot of the cliff begins to lose its verticality and dip at first steeply and soon more gently northwards. The stratification is clearly marked by bands of flints. At first the beds at the top of the cliff can be seen to be still vertical or slightly inverted, but later they too begin to bend round and dip northward (Text-fig. 3). At the region where this change takes place the chalk is much broken and cut by slickensided fractures in all directions, as described by Strahan, the zone of maximum disturbance being perhaps 30 feet thick. Soon a point is reached where a band of flints can be seen to dip steeply northwards and then flatten out rapidly without disappearing below beach level. A short distance farther all the chalk in the cliff is rising north-westwards (the true dip being south-east). Eventually the "Chalk Rock" rises from the beach, showing that we have passed the lowest vertical beds in Bat's Head, and finally the top of the Upper Greensand forms the ledge at the tip of White Nothe. The base of the Chalk continues to rise north-westwards until it is about 400 feet above the sea behind Holworth House.

Although Strahan admits that the cliff cuts this disturbance "so obliquely that it is difficult to interpret the section" and that "the actual fracture is lost in a belt of shattered chalk about 50 yards in width" (p. 220), he shows it as a definite fault hading north, cutting across the vertical chalk, upon which it superimposes the cut edges of the beds of chalk with a gentle northerly dip (Strahan, pl. ix). In accordance with his interpretation of the Swanage Fault, it becomes a thrust on the colour-printed map. But if as he states (1906–32, p. 10) the overthrusts in Durdle Cove are "small overthrusts springing from the main thrust" it is difficult to see how the main thrust can be in the opposite direction to its branches.

Now a careful examination of this section convinced me that a thrust-fault towards the south is out of the question. The section can be better interpreted without assuming the presence of a fault at all, even of normal throw. If there were a thrust-fault, the truncated ends of the displaced beds, where they lose themselves in the thick crush-breccia, as Strahan implies that they do, should curve downwards at their extremities. This might be all the more confidently expected since the fracture, as described by Strahan, is by no means a clean one. Actually there is no sign of any such



TEXT-FIG. 3.—Bat's Head from the west, drawn from a photograph taken in 1935. On the left and in the centre bands of flints in *quadratus*-zone chalk can be seen curving up towards the south. The zone of packed chalk rises up the cliff in the confused region opposite the boat and passes under the vertical portion forming the top of the cliff. Vertical to slightly inverted chalk down to the *planus*-zone forms the head on the right and is cut by innumerable small slicken-sided thrust-planes hading south.

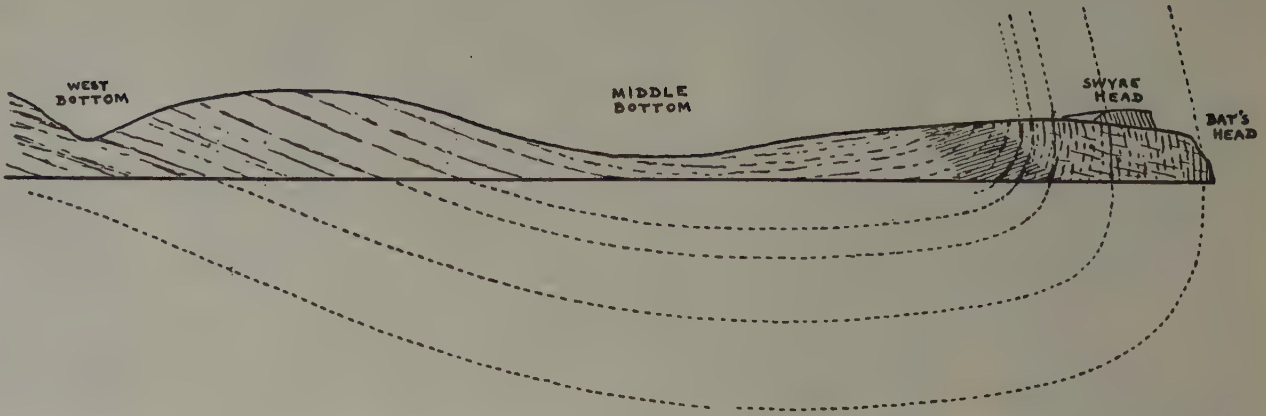
downward drag. On the contrary, the beds distinctly turn up towards the south as they approach the vertical chalk, and so steeply that they are soon parallel with it (see Text-fig. 3). I can find no fault-plane and no sign of the angular discordance shown in Strahan's drawing (his pl. ix). The cliff displays merely the lower bend of the Purbeck monoclinal fold or asymmetric anticline (Text-fig. 4).

Having come to this conclusion (much to my surprise), I was gratified on returning home to read the following description of the same discovery made over 120 summers earlier, during the first geological reconnaissance of the Dorset coast, by that acute observer Thomas Webster. In his letter to Sir H. Englefield from Weymouth, dated 1st July, 1812, he wrote as follows :—

" After rowing [from Lulworth] about a quarter of a mile to the west of Bat, I was much surprised to find that the strata of flints had become horizontal, without observing any apparent cause for this rapid change of position ; no appearance of disturbance in the strata being visible. To ascertain, therefore, in what manner the change from the vertical to the horizontal had taken place, I went still nearer to the cliff, and examined it more particularly. I could now perceive that these two portions were united by a series of curved strata : appearing to show that the chalk had been twisted, so as to have one part vertical and the other horizontal, the curves being probably produced by the section of the twisted part " (Webster, 1815, p. 195, and pl. xlvi).

Webster's description and drawing, and also W. D. Conybeare's (1822, p. 113), portray precisely what is to be seen at the present day, and I can only think that the cliff must have been unfavourably overgrown about the time of Strahan's survey.

Rowe (1901, pp. 7–8, and pl. i), who probably examined the chalk here more closely than anyone else, in the course of his zonal work, also failed to find any fault. His section drawn upon the photograph comprising his pl. i is the same as Webster's and Conybeare's and my own. But he seems to have been so impressed by what he calls the " lucid and graphical handling by Mr. Strahan " that he did not question that " the great fault " must come out somewhere hereabouts, and failing to find any break in the succession of Chalk zones in the high cliff west of Bat's Head, where Strahan marks the fault, he proposed shifting it westwards to Middle Bottom. His remarks are interesting (Rowe, 1901, pp. 7–8) : " It is difficult to fix the line of exit of the Isle of Purbeck fault. One view is that it may occur west of Bat's Head, where the beds sweep up in a bold curve ; another is that it takes place in the shattered chalk east of Middle Bottom, as indicated on Mr. Strahan's section ; and a third is that it may be found in the recess at Middle Bottom, where the chalk is shattered in every direction. We [I] incline to the last-mentioned view. In any case, if the fault runs out seawards at all near this point, there is nowhere any definite line of fracture."



TEXT-FIG. 4.—Section of the chalk cliffs west of Bat's Head, with Swyre Head behind. The shaded area represents the zone of packing in the axial plane of the syncline, which is the lower bend of the Purbeck asymmetric anticline. The lowest dotted line represents approximately the top of the *Holaster planus*-zone according to Rowe (1901, pl. i). The other dotted lines are inserted arbitrarily along bedding planes, to show the author's interpretation of the structure. The highest chalk represented belongs to the zone of *Actinocamax quadratus*. The length of the section is 1 mile, and the vertical scale is the same. The dip of the beds on the left is apparent dip; the true dip is much steeper.

In spite of this, Rowe could find no displacement in the *quadratus*-zone chalk of Middle Bottom (1901, p. 11, and pl. i), and I am satisfied that none exists. On his folding section (pl. ix) he copied Strahan and ran the fault out at the upward curve, between Middle Bottom and Bat's Head.

Now, the upper part of the cliff between Middle Bottom and Bat's Head, perhaps owing to the fall about 1910–13, at present clearly shows that the belt of most highly shattered chalk rises up from the beach obliquely northwards (inland) and that vertical chalk rests upon it near the top of the cliff and passes downwards into it (see Text-fig. 3). If the shattered rock is a fault breccia, the hade of the fault is in the opposite direction to that indicated by Strahan. But the rock does not in the least resemble a fault breccia. The shattering and slickensiding, and the gradual way in which they die out in the vertical and horizontal chalk above and below, suggest to my mind that they are the effect of the packing of the chalk in the concave side of the sharp fold forming the lower bend of the monocline. This belt of packing is just in the position in which it would be expected on theoretical grounds, along the axial plane of the fold.

(c) *General Considerations.*

This reinterpretation of the Bat's Head and Ballard Point sections makes the Purbeck disturbance as a whole for the first time intelligible. Any great southward thrusting, as postulated by Strahan, could not have occurred as part of the same movements that produced the steep monocline with its vertical limb to the north, in which the vertical strata were broken along numerous small thrust-planes and forced in the opposite direction (south to north). The southward thrusting would have to have occurred in an entirely separate later episode and could only have been brought about by pressures in the opposite direction from that in which came the pressures giving rise to the monocline. That there should have been such a reversal of pressure at a subsequent episode but still within the Middle Tertiary is not impossible, but it is not *a priori* probable. Nor is it probable that rocks which had reacted to pressure from the south by forming a large monoclinal fold or asymmetric anticline overdriving northwards, would react to pressure from the north in an entirely different way, by merely yielding along a thrust-plane. The previous disturbances had not been so violent that the rocks were consolidated by them, as by a major orogeny, so that subsequent yielding could only be by shearing. On the other hand it seems reasonable to suppose that, on the relaxation of pressure from the south, adjustment would take place by normal faulting. Furthermore, a fault so produced might be expected to make its appearance along the weakened and oversteepened northern limb of the monocline or anticline, already a line of instability, and especially near the centre of the fold where the amplitude was probably greatest. The brow was already bent so far forward that in places, at least, its weight was resting on the infolded foreland, and everywhere else upon the vertical or inverted and crumpled northern limb, already weakened by small thrust-planes and slickensided fractures. Along this overweighted belt, when pressure was relaxed, the crust gave way, and the brow of the monocline and the rocks under it seem to have flaked off and subsided northward as the downthrow of a normal fault. This occurred only near Swanage, which is about midway between the ends of the acute part of the fold at White Nothe and Brixton Bay in the Isle of Wight.

The recognition of the curved strata at Bat's Head as the lower bend of the monocline implies that the cliff here cuts the monocline at a lower horizontal plane than at Swanage. This is in accordance with the general easterly tilt of the country, which brings the lowest strata to the surface on the west coast of Purbeck and raises Oligocene beds to 637 feet above sea-level on Creech Barrow. By it too the Jurassic foundation is exposed below the Chalk in the foreland of the fold about Ringstead and Osmington and the basal Eocene outliers form the highest hills in the district at Black Down, while the foreland north of Swanage is thickly loaded with Eocene strata at sea-level. A continuation of the same tilt has caused the survival of Oligocene strata at sea-level on the immediate foreland in the Isle of Wight.

The section from Ringstead Bay round White Nothe to Bat's Head and Durdle Cove is a complement of that from Freshwater Bay round the Needles to Totland Bay. At first sight the sections are very different, but they lie near the opposite extremities of the same monoclinal fold and their differences are due almost entirely to the differences in the horizontal plane at which the S-shaped fold happens to be cut by the cliffs. The Isle of Wight shows us the upper curve of the " S " in the Chalk, Lulworth the lower. What is visible in the Isle of Wight has been removed by denudation near Lulworth, and what is visible near Lulworth lies deep below sea-level in the Isle of Wight.

By measuring the difference in level between the base of the Chalk on the axis of the anticline near Brook and under the Tertiary trough by the Solent (about 4,800 feet; see White, 1921, p. 150) we are perhaps justified in estimating that the base of the Chalk turned over to the horizontal as much as 4,500 feet above the sea off Bat's Head.

3. THE RELATIONS OF THE TERTIARY TO OLDER MOVEMENTS.

In tracing earth-movements in the South of England the standard of reference is generally the Chalk, with the Upper Greensand and Gault. We either note the forms into which the Chalk has been folded or faulted, or reconstruct the forms that the Jurassic rocks had already assumed when the Chalk was laid down. Since it formerly overspread the whole of South-East England, it can safely be assumed to have been everywhere approximately horizontal when deposition ceased.

In the Isles of Wight and Purbeck the Chalk and Albian appear to be perfectly conformable with the vast thicknesses of Aptian, Wealden, Purbeck, Portland, and Kimeridge sediments underneath. They all take part in the fold, and there is no reason to suspect the existence of any Mesozoic folds or faults. This, however, is only the backland of the fold. Farther west, the continuation of the axis of the Purbeck fold passes approximately through the centre of the Weymouth Anticline, of flatter but essentially similar structure (the steeper limb to the north) in the centre of which earlier Jurassics down to Fuller's Earth (Bathonian) come to the surface (Text-fig. 5). Here again the rocks of the southern, flatter limb or backland are relatively undisturbed. The gently sloping tablelands of Portland Island and the Weymouth promontory are comparable tectonically with the tabular uplands of southern Purbeck and the south of the Isle of Wight, and both stand in strong contrast to the complex foreland.

When we examine the northern limb of the Weymouth Anticline and the tract to the north of it, we find a very different history. Here, in a long strip from Ringstead Bay to Abbotsbury and Bridport, where the Chalk and the Jurassic foundation under it have been exposed by denudation in the foreland of the fold owing to the easterly tilt, a series of pre-Albian east–west folds and faults is revealed. The Aptian (Lower Greensand) is missing, and the Albian (Upper Greensand and Gault) transgresses unconformably across the eroded edges of the folds and faults. All the rocks up to the Wealden Beds inclusive are involved in the movements, which, with the erosion, must therefore have taken place some time in the interval between the Wealden and the Gault: i.e. approximately in the Aptian period, when the foreland of the fold hereabouts was emerged.

Some idea of the differences in the stratigraphical column below the Albian as we proceed westwards and then north-westwards from the backland on to the foreland of the Purbeck fold can be obtained from the following comparisons of thickness :—

	Upwey (*13 miles*) ft.	*Worbarrow.* (*10½ miles*) ft.	*Swanage.* ft.
Lower Greensand .	0	137	198
Wealden Beds . .	*c.* 450	1,237	2,350
Purbeck Beds . .	190	290	397
Portland Beds . .	130	204	220
	770	1,868	3,165

These figures may give an inaccurate impression because at Upwey there may have been some squeezing such as Strahan averred reduced the thickness of the Wealden and Purbeck Beds by 75 per cent at Durdle Door (though whether squeezing to such an extent really occurred seems doubtful). The thinning, too, may be as much westerly as northerly. But it is at least suggestive that between the time when the Portland Beds began to be deposited and the end of the Lower Greensand period there were probably about four times as much subsidence and sedimentation under the site of the axis of the fold in the east of Purbeck as on the edge of the foreland north of the Weymouth Anticline.

These facts give some grounds for believing that the Purbeck-Brixton monocline and its continuations the Sandown and Weymouth monoclines arose along the northern margin of a Jurassic and Lower Cretaceous trough, deepening southwards, in the same way as the Hogs Back monocline arose along the northern margin of the Weald trough. The fact that both folds overlook a deep Tertiary-filled basin leads to speculations on the underground geology of the Hampshire Basin by analogy with that of the London Basin (Arkell, 1933). But the Purbeck monocline is much steeper-limbed than that of the Hogs Back, and the bends of the S are sharper. Moreover, the numerous small flat-lying thrusts of Purbeck and Lulworth are not strictly comparable with the single steep thrust or reversed fault of the Hogs Back, as portrayed by Dines and Edmunds (1927, pl. 13). As will be shown below, the structure of the Hogs Back shows more points of resemblance with the Ridgeway Fault.[1]

These general remarks are made here by way of introduction to the Ridgeway Fault and its associated faults and folds north of the Weymouth district. Strahan stressed the analogies between the Ridgeway and Purbeck disturbances, as I believe to the detriment of our understanding of either. It should be emphasized that the Ridgeway Fault and associated smaller faults and folds (Ringstead, Chaldon, Litton Cheney) lie on the foreland of the major Isle of Wight-Purbeck-Weymouth Anticline; that from at least the beginning of Portlandian times onwards to the beginning of the Albian the ground on which they were to come into being was being prepared differently from that under and behind the major fold; and that consequently it is unlikely that the effects of the Tertiary earth-movements in the two areas would be strictly comparable.

Actually the Tertiary movements of the Chalk in the area north of Weymouth, as Strahan showed, were much influenced and complicated by the intra-Cretaceous structures with approximately parallel but locally oblique strike.

---

[1] Dines and Edmunds (1927) spoke of the " close parallel with the Dorset overthrusts described by Strahan " ; but at the time they wrote the current interpretation of the Dorset faults by Strahan gave no grounds for drawing any parallel, which now for the first time becomes possible. On Strahan's view the force must have come from the opposite direction, as described above.

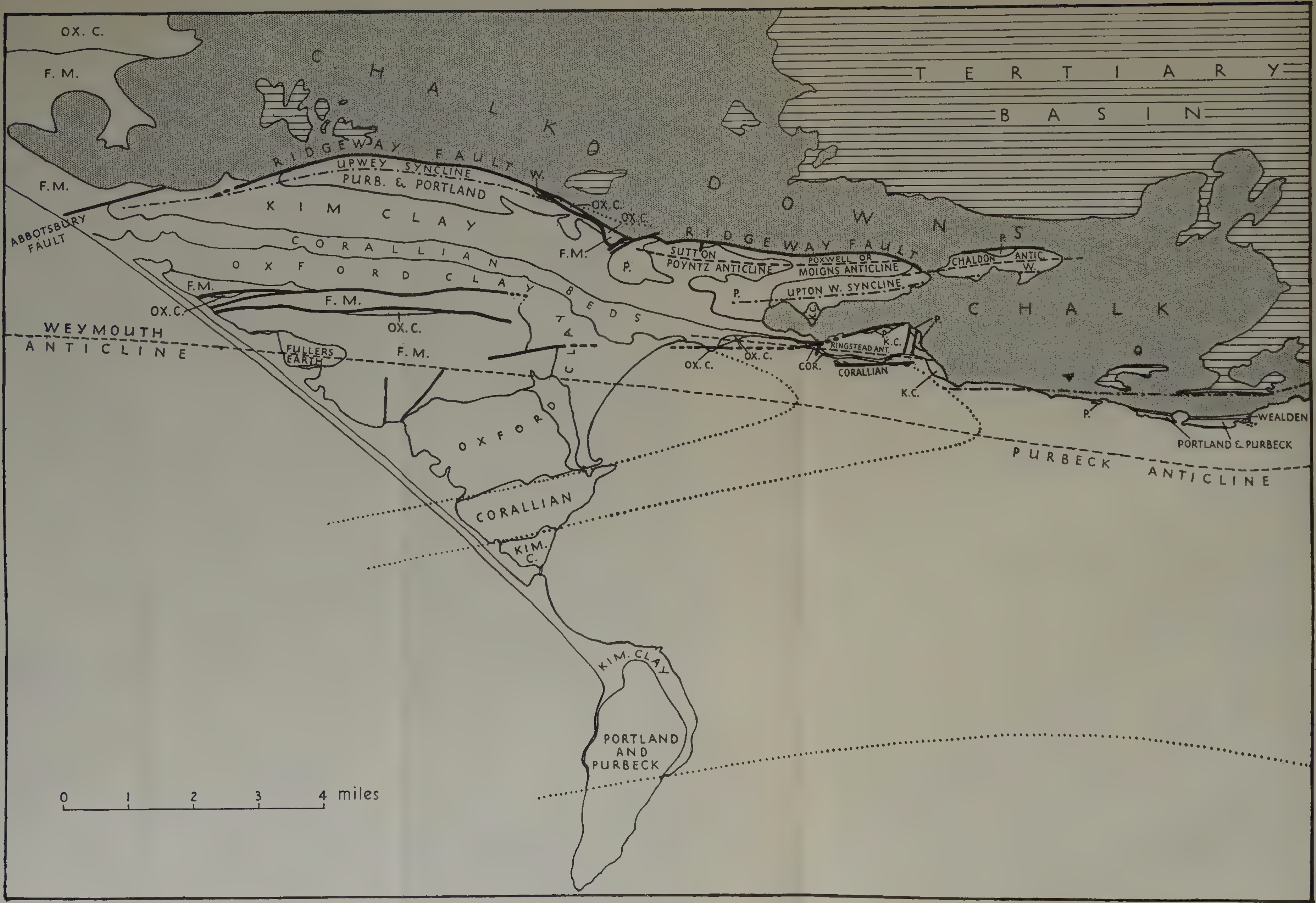
4. THE RINGSTEAD, CHALDON, AND OTHER SUBSIDIARY FOLDS ON THE FORELAND.

For 15 miles, from Swanage to Durdle Door near Lulworth, the Portland and Purbeck Beds remain apparently parallel to the base of the Albian and take part in the simple Tertiary fold. The Cow and Calf Rocks and others on the same line show that the Portland Stone, nearly vertical, continues on the same strike and with the same conformable dip as far as Bat's Head, little more than a mile from White Nothe. Yet directly we cross the vertical limb of the Purbeck monocline northwards into the foreland, by rounding White Nothe into Ringstead Bay, we find already violent angular unconformity between the Albian and the underlying Jurassics (see map, Text-fig. 5).

The first horizon on which we find the Albian reposing under White Nothe is in the middle part of the Kimeridge Clay. The base of the Gault rises in just over half a mile from sea-level to 400 feet and rapidly intersects the Portland and Purbeck Beds, which dip in the opposite direction, to the north, and are twice cut by pre-Albian dip-faults striking approximately north–south. The Albian and Chalk then plunge down steeply northward again, as described by Strahan, to form the narrow and perhaps gently synclinal tongue of high ground which stretches 2½ miles westward to Osmington. There is therefore here a second asymmetric anticline in the Chalk, which Strahan calls the Ringstead Fold, and the steep northern (probably faulted) limb corresponds for at least part of its course (near South Down Farm) with the gentler northern limb of a broader intra-Cretaceous (pre-Albian) fold with east–west axis. Here the Tertiary and intra-Cretaceous movements seem to be more or less superimposed and, although the Upper Greensand and Chalk are nearly horizontal on Coggins Barrow and Black Head, it is impossible to estimate how much of the extremely steep northerly dip of the Corallian Beds in the cliffs and foreshore a little way to the south is due to the original intra-Cretaceous movements and how much to the Tertiary. The evidence is ambiguous.

The Ringstead Anticline dies out in the Corallian Beds and Oxford Clay a short distance west of Ham Cliff, north of Redcliff Point.

The northerly dip of the Jurassics carries them down into the narrow Upton Syncline, filled by Wealden Beds which are likewise folded, and this syncline is continued eastwards partially under the Upper Cretaceous past Upton to near Chaldon Herring. Parallel to the Upton Syncline and to the north runs the Sutton Poyntz-Moigns or Poxwell Anticline, 4 miles in length and with an exactly east–west axis, the eastern part extremely narrow and steep (Poxwell Circus and Moigns Down), the western end broadening out and flattening west of Sutton Poyntz. These structures, which



Text-fig. 5.—Tectonic sketch-map of the Weymouth district. Faults: thick lines. Axes of anticlines: broken lines. Axes of synclines: broken and dotted lines; the supposed continuation of the Upwey Syncline under the Chalk is dotted. The dotted lines in the sea represent the supposed strike-lines at sea-level of the top and bottom of the Corallian Beds and the top of the Kimeridge Clay (generalized). The Ringstead anticline is the intra-Cretaceous axis. Abbreviations: F.M. = Forest Marble and Cornbrash; OX.C. = Oxford Clay and Kellaways Beds; COR. = Corallian Beds; K.C. and KIM.C. = Kimeridge Clay; P. = Portland and Purbeck Beds; W. = Wealden Beds. Outcrops from the Survey maps, and also the faults in the district west of the meridian of Weymouth. The Abbotsbury Fault should curve to the south as it approaches the sea, more than shown. The area stippled includes the outcrops of the Albian and Chalk.

To face p. 73.]

were admirably worked out by Strahan, need not be any further described.

The Chaldon inlier of Wealden and Purbeck Beds is continuously surrounded by unconformable Upper Cretaceous, and from the dips Strahan established beyond question that there was here a Tertiary Chaldon Anticline (or pericline). Similarly, the dips and lie of the Upper Cretaceous round three sides of the Poxwell-Sutton Poyntz Anticline and Upton Syncline suggest that these structures were together the site of a pericline in the Chalk about 4 miles long and 1 mile wide, flattening out westwards.

If the axis of the Upton Syncline is continuous with the synclinal axis in the Wealden inlier at Chaldon, it makes a north-easterly bend oblique to the axis of the Tertiary folding. It is noteworthy that at the point where this bend seems to take place, at Holworth Farm, there is a corresponding oblique synclinal cross-fold in the Upper Cretaceous, with opposite strike, which has led to the survival of a little " bridge " of Albian, separating the Tertiary pericline of Chaldon from that to the west.

To summarize, therefore: it can be said that although these folds do not show strictly posthumous activity, a fairly close relationship can be traced between the earlier structures and the later superimposed upon them. But the later movements were feebler and sometimes in the reverse sense.

It is probably legitimate to compare the minor Tertiary folds on the foreland hereabouts to the small axes traced in the Tertiaries of the Isle of Wight (see White, 1921, p. 149, fig. 30).

[*To be concluded.*]

The Tertiary Dykes of the Craignish Area, Argyll.

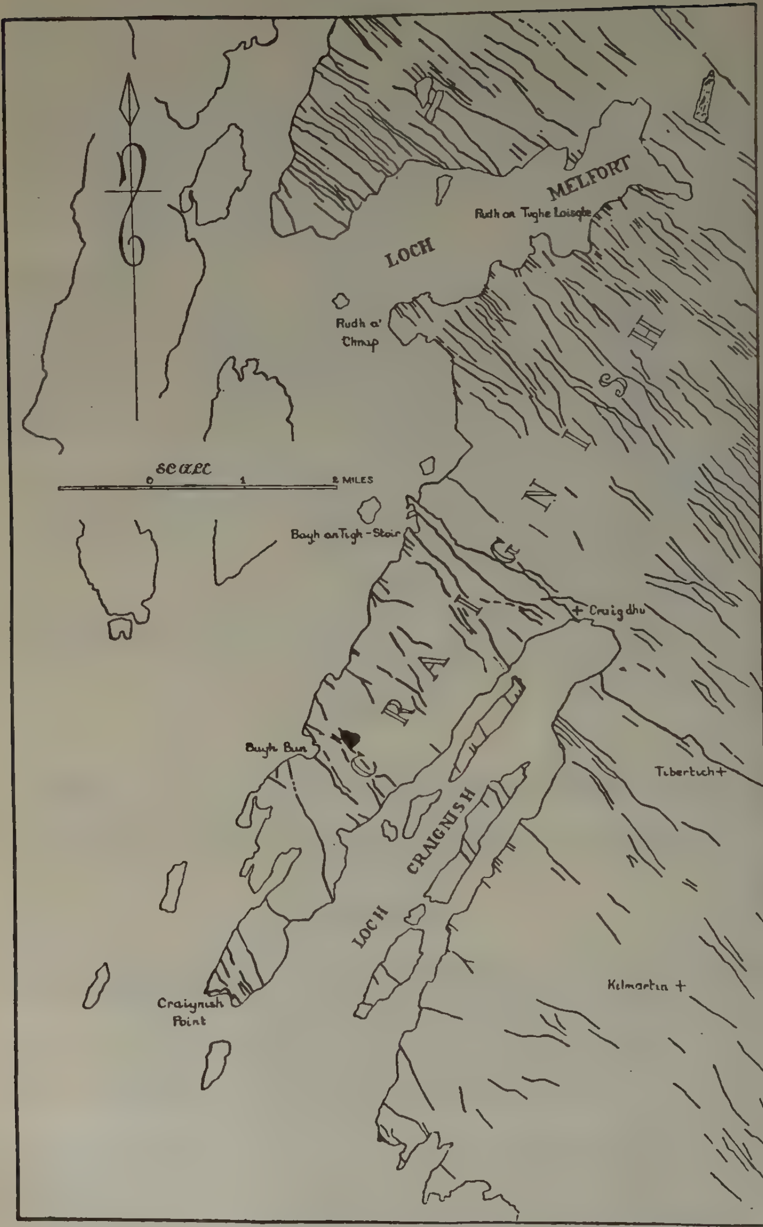
By Archibald Allison, Department of Geology, Glasgow University.

I. Introduction.

FOR our present purpose the Craignish Area is considered to include the peninsula of Craignish and its adjoining parts, as shown in the sketch-map, Text-fig. 1.

A general description of the Tertiary dykes of the area by various officers of the Geological Survey, with petrology by Sir J. S. Flett, will be found in the official memoir on Sheet 36 (Flett, etc., 1909, pp. 80–91).

It is of interest that in this memoir H. B. Maufe, by treating the north-west dykes as a unit, offered an early contribution to the conception of a " dyke swarm " (1909, p. 82), an idea which, in its application to the present area, was more fully developed by E. B. Bailey in the *Mull Memoir* (1924, pp. 52, 359).



TEXT-FIG. 1.—Sketch-map of Tertiary dykes in the Craignish Area, Argyll.

The following notes are intended only to supplement the descriptions given in *Mem. 36* (1909) in the light of recent knowledge and with particular reference to the *Mull Memoir*.

II. GEOLOGY.

The focus of the Mull igneous complex is roughly 20 miles distant from the head of Loch Craignish. Numerous dykes, striking from north-west to south-east, belonging to the Mull swarm, cross the Craignish Area. Indeed, H. B. Maufe (1909, p. 82) states that in certain sections, over a mile traverse, it is possible to count between thirty and forty dykes. On the bare rocky shelf of the 25 ft. raised beach from Craignish Point to the eastern end of Loch Melfort there is an excellent opportunity of examining practically every dyke which passes into the area and of measuring individual widths with some degree of accuracy. In this distance of approximately 10 miles 123 dykes were noted.

The aggregate thickness of these dykes is 1,311 feet, and amounts to a stretch of about ¼ mile in 10 miles, represented by the ratio 1/40. In South-Central Mull the stretching is estimated as ½ mile in 12½ miles, or 1/25 (Bailey, 1924, p. 360). In Arran the stretch is given as 1/14·4 (Tyrrell, 1928, p. 249).

The average thickness per dyke in the Craignish area is 10·6 ft., that in Mull 5·8 ft., and that in Arran 11·5 ft. There are thus fewer but on an average broader dykes in the Craignish area than in Mull.

A consideration of measurements shows that there are several very broad dykes in the area. A composite pitchstone north of Bagh an Tigh Stoir, Craignish, is 50 feet broad, while a dolerite north of Rudh a' Chnap, Loch Melfort, is 70 feet across. These are, however, exceptional.

The total width of thirty-three crinanites and allied dolerites is 545 feet, or 16·5 feet per dyke. Twenty-seven tholeiites and allied fine-grained basalts measured 170 feet, which is on an average 6·3 ft. each. Apart from pitchstones the more acid dykes are thinner. This is likewise the case in Arran.

III. CLASSIFICATION.

The classification adopted is based on that used in the *Mull Memoir*, and according to the type of parent magma.

Plateau Type.—Crinanites and other olivine-dolerites and basalts including one ultra-basic type.

Non-porphyritic Central Type.—Tholeiites and allied basalts. Variolites.

Porphyritic Central Type.—Dolerites and basalts, often tholeiitic, with porphyritic felspar.

Intermediate to Sub-Acid Type.—Leidleites and allied andesites, sometimes as pitchstones.

Dykes of Doubtful Age.—Monchiquite.

In *Mem. 36* Flett did not treat rocks merely distinguished by the presence or absence of porphyritic felspar as separate types. Also he used the term teschenite for what he afterwards defined as crinanite, taking the name from Loch Crinan at the southern extremity of the present area (Flett, 1911, p. 117).

IV. PETROLOGY.

(*a*) *Plateau Type.*

Dykes of this type include ophitic olivine-dolerites and basalts and similar rocks, crinanites, bearing analcite and zeolites.

Dolerites and crinanites are very common in the district over its entire length and breadth. At the southern end of the Craignish peninsula, at Craignish Point, these dykes predominate, and especially good exposures are here seen.

The essential minerals are basic plagioclase, labradorite, as laths; olivine; brown or lilac augite; and iron ore. Accessories are apatite, analcite and biotite in small amount, associated with iron ore. The zeolites, natrolite and thomsonite, generally occur along with analcite. It is characteristic that plagioclase and augite crystallize together, so that the latter is rarely idiomorphic but generally ophitic. This sometimes produces poikilophitic texture or ophimottling.

The olivine of the crinanites is rarely fresh. This feature of analcite-bearing rocks has been noted by Flett (1930, p. 63). The products of alteration are identified as mainly bowlingite (iddingsite) and antigorite. The bowlingite agrees with the mineral in lavas from the Kilpatrick Hills, and with the description given by A. N. Winchell in *Elements of Optical Mineralogy* (1927). A little brown biotite sometimes occurs as a rim to pseudomorphous antigorite and bowlingite, in which position it is probably a late reaction product between olivine and magma. A similar type of alteration was noted by W. G. Tidmarsh (1932, p. 735) in the olivine xenocrysts of the Permian lavas of Devon.

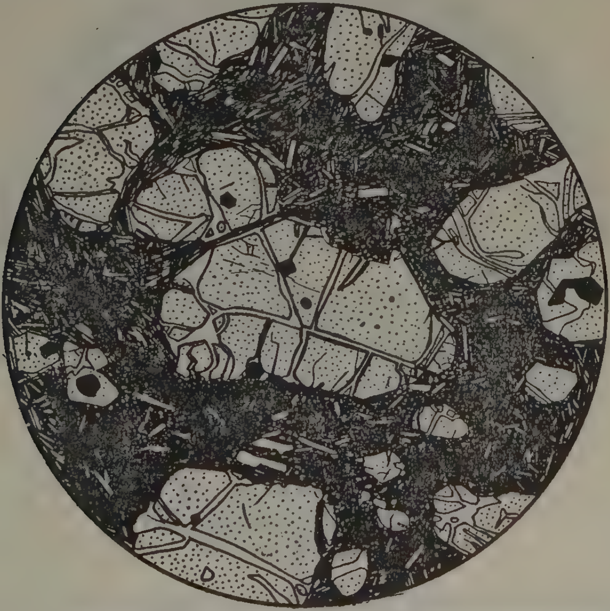
A small ultra-basic dyke 1 foot thick, occurring beside a tholeiite in a stream 1 mile north-east of Kilmartin, may, from its composition, be included in this group. The dyke contains abundant idiomorphic phenocrysts of fresh olivine, about 2 × 1 mm., in a matrix of immature crystallization. The latter contains labradorite felspar laths 0·1 to 0·2 mm. long; much iron ore dust; obscure monoclinic pyroxene and felspar microlites; with some glass (Text-fig. 2). A few sporadic phenocrysts of plagioclase, 1 × 0·5 mm., showed corrosion by the magma.

This dyke appears similar to a thin dyke described as occurring in Glen Rosa, Arran. It may represent a late expression of magmatic differentiation, but clearly is in no way immediately allied to the large dyke with which it is associated, as the latter is a pigeonite-bearing tholeiite of Talaidh type.

(*b*) *Non-Porphyritic Central Type.*

Rocks representative of this type include olivine-free, or olivine-poor, basalts, which may have small amounts of uncrystallized base; tholeiites, variolites, and a rock allied to augite-diorite.

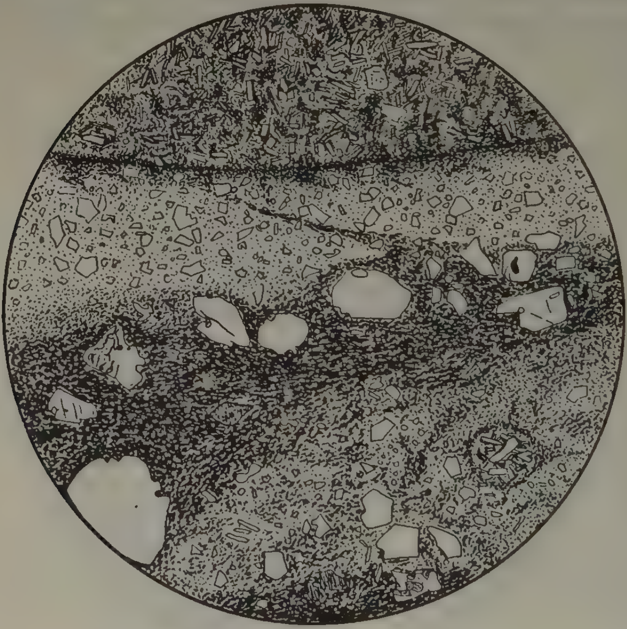
The constituent minerals are augite, plagioclase, and iron ore, with or without olivine. Though typically non-porphyritic, sporadic plagioclase phenocrysts are not uncommon in tholeiites. The augite is pale brown, but tends in more acid rocks to be colourless. Correspondingly, ophitic gives place to intergranular texture, and a columnar habit is assumed by the pyroxene. Varying amounts of mesostasis may be present, as glass, or its devitrification product.



TEXT-FIG. 2.—Olivine-rich tholeiite, dyke, 1 mile north-east of Kilmartin. Shows olivine phenocrysts (2 × 1 mm.) in a matrix of immature crystallization.

Basalts of this class are quite numerous. They are fine-grained and often contain small amounts of uncrystallized base. With increase in the amount of the latter they come under the heading of tholeiites.

Four olivine-bearing tholeiites, Salen type, have been identified. One of these at Rudh an Tighe Loisgte, Loch Melfort, is apparently the dyke described by Flett (1909, p. 87). Five tholeiites of Brunton type were examined, in which olivine sometimes sparingly occurs. Talaidh tholeiites are moderately common, and were of greater variety of interest, as in this group types transitional to the augite-andesites were encountered. Thus the dyke in the stream 1 mile north-east of Kilmartin contains phenocrysts of pigeonite, while some hypersthene is present in the ground mass. Again the acicular pyroxene in a dyke south of Rudh an Tighe Loisgte is entirely the uniaxial variety, pigeonite. Some of the Talaidh tholeiite dykes are also certainly composite and have less glassy margins. Indeed, another dyke at Rudh an Tighe Loisgte, bearing fritted and cracked phenocrysts of brown augite, had margins which were holocrystalline, and contained olivine.

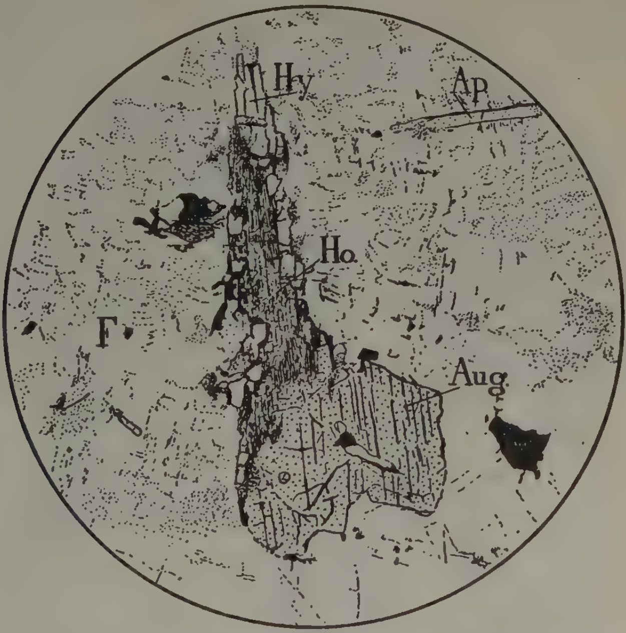


TEXT-FIG. 3.—Microscopic brecciation due to explosion in tholeiite dyke, 1 mile north of Bagh Ban, Craignish.

Explosive phenomena have been noted in two tholeiitic dykes in the area. Such occurrences have previously been described in dykes near Loch Feochan, north-east of the present area, in sheet 45 (scale 1 inch = 1 mile), and in Mull and Arran.

In one case about 1 mile north of Bagh Ban, Craignish, the brecciation is on a microscopic scale only. The dyke contains abundant brown augite; some olivine pseudomorphs; plagioclase laths and phenocrysts; iron ore and a little glass. It might be designated a tholeiitic basalt. In a particular thin section this dyke was seen to be veined by fine material, which was darkened by iron ore particles and contained microscopic augite prisms, felspar laths, with occasional rather large pseudomorphous olivine phenocrysts. Also present were abundant angular fragments of plagioclase from the mechanical disintegration of phenocrysts (Text-fig. 3).

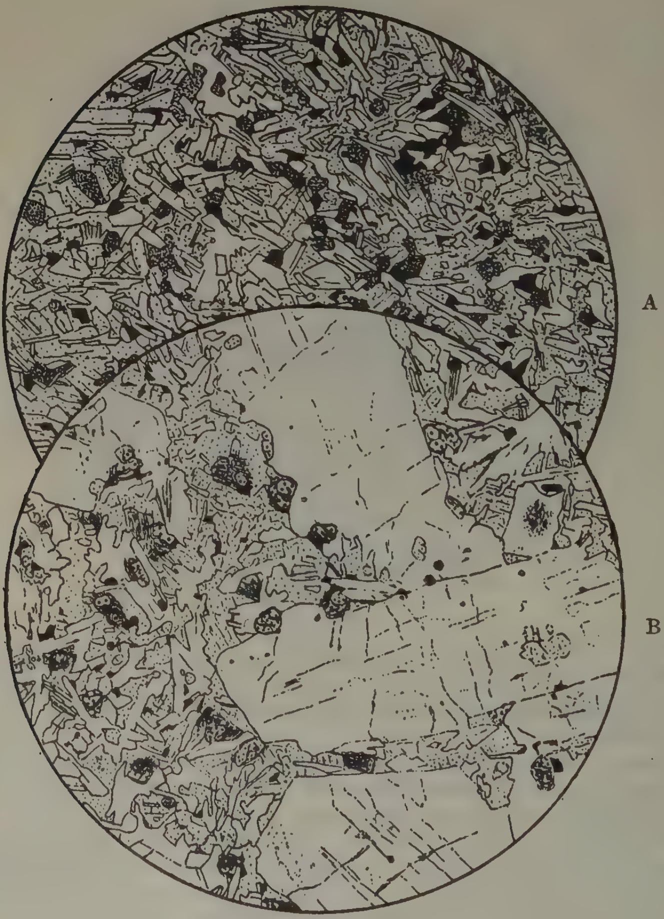
Brecciation on a larger scale is seen in a dyke exposed on the foreshore at Rudh an Tighe Loisgte, Loch Melfort. This dyke is 6 feet wide and has a central " bouldery " portion. The sides of the dyke are unbroken and are a fine-grained type of olivine-poor basalt with a small amount of residual glass. The " boulders " are coarser in texture. They consist of an olivine-bearing rock, which is texturally a good example of Brunton tholeiite. The material between the " boulders " is composed of angular fragments of the same Brunton tholeiite separated by comminuted material containing many secondary infiltrations of quartz and calcite.



Text-fig. 4.—Augite-diorite, Barr Mor, showing effects of auto-pneumatolysis. F, felspar altered to muscovite and chalcedony (?); Aug, augite altering to brown hornblende (Ho) and hypersthene (Hy); Ap, apatite.

Variolites are not common in the district, and only two were microscopically examined. One of these is 1 ft. thick, and was described by Flett (1909, p. 89). A second, 7 feet thick, is exposed at the north point of Bagh Ban, Craignish.

The plug-like mass, Barr Mor, ¼ mile east of Bagh Ban, is included in this group, having affinities with the augite-diorites of Mull. The rock is coarse in texture. It contains olivine as pseudomorphs; brown augite; plagioclase of normal composition, often zoned with albite; much apatite; iron ore; and interstitial analcite. Portions of the rock show the results of extreme reaction due to auto-pneumatolysis. A small amount of brown hornblende and much clear hypersthene have been produced. The former is certainly secondary after augite and there is some evidence that the latter may be of similar origin. The felspar has, in such areas, been attacked with the formation of muscovite and chalcedony (?) (Text-fig. 4).



Text-fig. 5.—Composite dyke, basalt of porphyritic central type. A, non-porphyritic selvage; B, porphyritic basalt of central part.

(c) *Porphyritic Central Type.*

Dykes of this character are fairly common in the district, and were noted by Flett (1909, p. 86) in the section devoted to ophitic olivine-dolerites. Almost invariably these dykes are composite, and have non-porphyritic selvages about 1 foot thick (Text-fig. 5).

In the *Tertiary Mull Memoir* composite intrusions are described of the type having an acid core and basic margins. It is assumed that acid magma being viscous cannot readily penetrate fissures unless they happen to be preheated by a preliminary injection of more fluid basic magma. It has been suggested, however, by N. L. Bowen, in *The Evolution of the Igneous Rocks*, p. 158, and in an addendum by E. B. Bailey, p. 173, that a magma may be rendered viscous by early formed crystals. Accordingly a composite intrusion will be formed, because the porphyritic magma must be preceded by an injection of more viscous non-porphyritic magma.

On the other hand, W. Q. Kennedy (1931) has shown that in Renfrewshire, Skye, and Etna, magma containing porphyritic felspar may succeed non-porphyritic magma as part of a single lava flow. Though Kennedy does not suggest it, we might assume that the porphyritic portion here represents magma into which, previous to eruption, felspar phenocrysts had fallen from an overlying layer, the latter in consequence becoming non-porphyritic. In this case, upon injection into fissures, porphyritic magma will follow non-porphyritic for the reason that in the reservoir it is the underlying stratum. Probably both principles must be considered as contributing to the observed results.

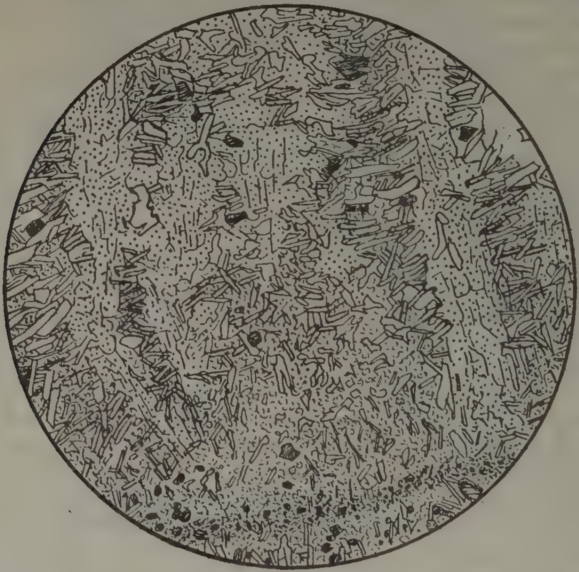
We may regard the central portions of these dykes as consisting of two components, phenocrysts and matrix. The phenocrysts are labradorite felspar, rarely anorthite. Zoning with the formation of more acid rims which may be andesine is general. Impregnation by magma is frequent. Olivine phenocrysts are rare.

The matrix to the phenocrysts varies considerably but is, in general, an olivine-basalt, which may have tholeiitic affinities. In one extreme case olivine was very subordinate and hypersthene was present as phenocrysts and in the ground mass. This was typically zoned with monoclinic pyroxene.

The marginal facies reproduce the features of the matrix, but are frequently more basic in appearance.

An interesting intrusion ¼ mile north-east of Rudh an Tighe Loisgte forms a flat sill, 3 feet thick, conformable with the bedding of the phyllites. This rock shows labradorite felspar phenocrysts, set in an olivine-basalt matrix with a small amount of residual glass. The intrusion is composite, but has a banded appearance, with three porphyritic members, separated by non-porphyritic layers. The central portion, B, has non-porphyritic margins with chilled edges that were probably originally in contact with the phyllites. A section across the junction of the central band and one of the marginal bands is interesting, for it shows augites ranged in columns normal to the margin, and apparently cutting almost at right angles across rows of felspar laths that have been oriented by fluxion parallel with the edges (Text-fig. 6).

Two porphyritic dykes examined were not composite, but are in other ways exceptional. One of them, about 1 mile north of Craignish Point, approaches the Big Felspar type of Mull. Tabular phenocrysts of labradorite felspar measure up to 2 in. × 1½ in. These are cracked and veined by infiltrations of basaltic matrix. The second dyke occurs west of Kilchoan, on the north shore of Loch Melfort. This dyke, which has a decomposed and crumbled appearance, is crowded with felspar phenocrysts of normal composition, together with a good number of olivine phenocrysts.



Text-fig. 6.—Section across junction of members of composite dyke of porphyritic basalt.

(d) *Intermediate to Sub-Acid Type.*

The only previous reference to any dyke of this group (Flett, 1909, p. 89) concerns the central glassy portion of the dyke forming the cliff feature behind Craigdhu Farm, Craignish. This dyke is in reality a composite intrusion with a glassy core and stony margins. Sometimes, as on the foreshore at Craigdhu, it shows " sheath and core " structure. The mineral assemblage is hypersthene, as phenocrysts; elongated augite; labradorite; and iron ore. The central portion contains abundant evenly-distributed glass. The extreme margins, however, are tholeiitic in texture, and are even more crystalline than the stony facies a few feet from the edge, which resembles the leidleite type.

A second dyke of similar character is exposed on the shore 1 mile west-south-west of Rudh an Tighe Loisgte, Loch Melfort. It is 15·5 ft. thick, with a distinctly lenticular central portion 5 feet across, much veined by quartz. The dyke contains, except at the edge, phenocrysts of ûniaxial pigeonite with rounded outlines and sometimes twinned; and phenocrysts of plagioclase, slightly zoned and much corroded. The minerals of the matrix are plagioclase; elongated crystals of augite, some hypersthene, and iron ore. The mesostasis of the glassy centre, an abundant brown glass containing felspar trichites and iron ore particles, shows "sheath and core" structure on a microscopic scale (Text-fig. 7 A). The stony margins are less glassy and of tholeiitic texture (Text-fig. 7 B); but at the outer edge are represented by a holocrystalline quartz-basalt rock with irregular ophitic plates and granules of augite, plagioclase laths, and iron ore (Text-fig. 7 C).

A third glassy dyke occurs about 1 mile north of Tibertich. This dyke may be one of those mentioned by Flett in *Mem.* 36, p. 88. It is 20 feet broad, porphyritic, with a wide glassy centre and stony margins. Constituent minerals are plagioclase in phenocrysts and laths; elongated augite; hypersthene (cf. enstatite, Flett, 1909, p. 88); and iron ore. Phenocrysts of labradorite and anorthite are present. The augite is often moulded on and seemingly replaces hypersthene. There is a glassy base which decreases in amount towards the margins of the dyke.

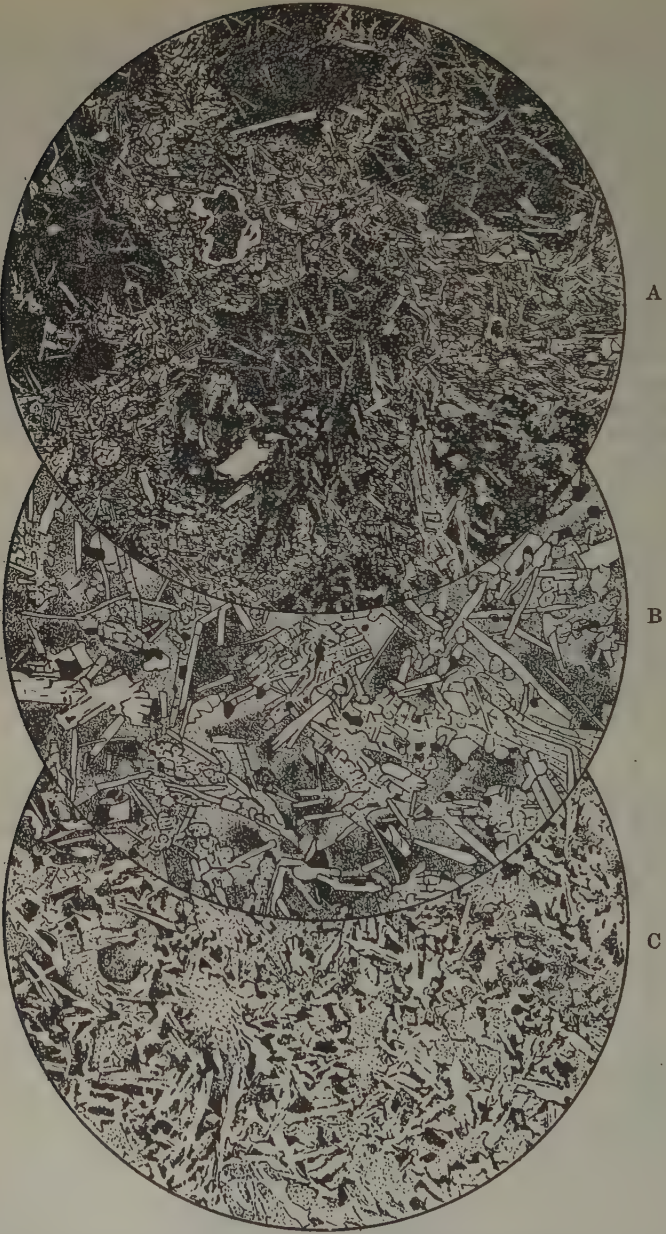
(*e*) *Dykes of Doubtful Age.*

The north-east to south-west dyke in the bedding of the phyllites, 200 yards north of Bagh Ban, falls into this category. It is a monchiquite containing phenocrysts of augite and pseudomorphous olivine. In the groundmass is plentiful augite and some pleochroic red hornblende. All the crystalline elements are idiomorphic and are set in a base of analcite, turbid with felspar microlites. The augite is lilac-tinted and the phenocrysts are deeper in colour at the margins. This is in keeping with pronounced zoning which may result in hour-glass structure. Hornblende is frequently moulded on the groundmass augite. The analcite may be collected into pockets with cores of clear material, associated with calcite. The turbid analcite in the pocket around the core contains hornblende, but no pyroxene. This feature recalls the ocellar structure of the camptonites (Flett, 1909, p. 91).

V. XENOLITHS.

(*a*) *Cognate Xenoliths.*

Cognate xenoliths are not a feature of these dykes. One example, however, may be noted. Close to Creag Aoil, near Rudh an Tighe



TEXT-FIG. 7.—Composite dyke of leidleite, Craigdhu, Craignish. A, glassy centre; B, stony tholeiitic margins; C, holocrystalline quartz-basalt at contacts.

Loisgte, a dyke 1 foot thick lies beside a broader dyke. The thin dyke is subvariolitic in texture, and carries clots, several inches across, of felspar crystals. The broader dyke is of porphyritic central type.

(*b*) *Accidental Xenoliths.*

Accidental xenoliths are also uncommon. Two only can be mentioned. These were each about 2 feet across, and had a superficial resemblance, being composed of whitish crystalline material set in a dark green glass.

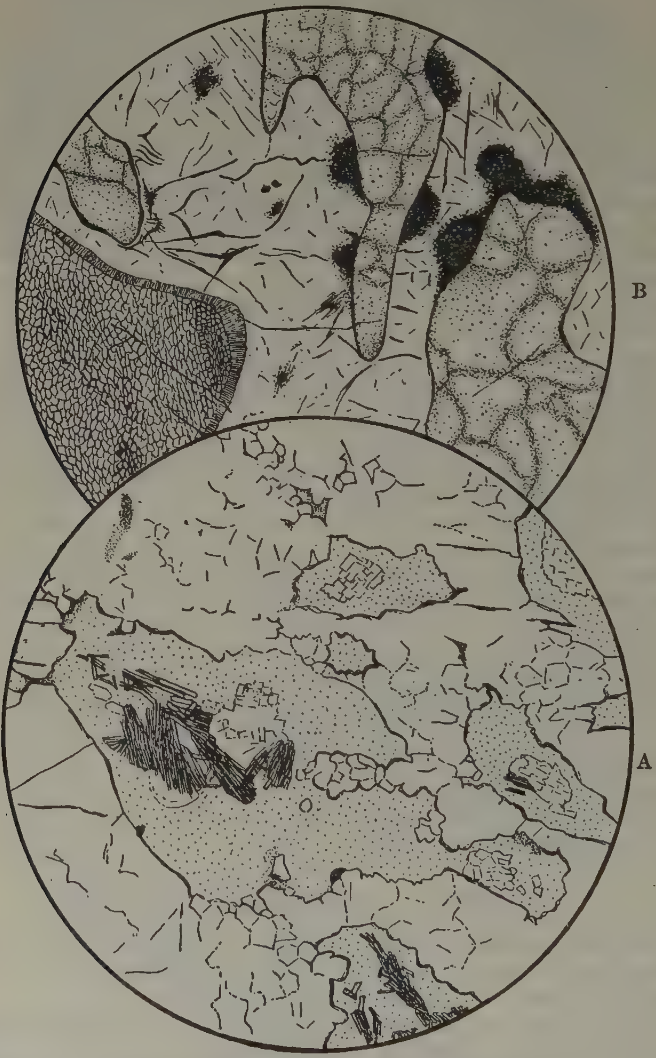
One of the xenoliths is a buchite, similar to those described by H. H. Thomas from Mull. It occurs in an olivine-free basalt just south of Bagh an Tigh-Stoir, and no doubt is an altered fragment of the Craignish Phyllites common in this locality. The xenolith contains globular clots of crystalline quartz, a little cordierite, pink mullite needles, black spinel (?), and glass. The clots of quartz have fretted and rounded outlines against the glass, which is colourless, and in which have crystallized the other elements (Text-fig. 8 A).

The second xenolith is of siliceous character and was found in a quarry at Tibertich, in the leidleite facies of the continuation of the Craigdhu dyke. The xenolith contains quartz and felspar aggregates which have rounded contours and dovetail into each other (Text-fig. 8 B). Between the aggregates intervenes a band of an unidentified reaction mineral, and generally some glass. The reaction mineral is in the form of colourless fibres normal to the surface of the felspar. Its formation, and that of the glass, illustrate the principle that two dissimilar substances fuse at their junction at a lower melting point than either. Owing to reheating, the felspar has almost entirely broken down into granules which, however, under polarized light extinguish in the same position, denoting that the optical continuity of the original crystal has not been destroyed. Cleavage and twin-planes are obliterated except in a few cases, from which it was possible to determine the presence of andesine felspar. Between each granule is a veneer of material of lower refractive index, which may be glass, or more acid felspar. (Cf. Tidmarsh.) The appearance of the felspar recalls the "finger-print" structure noted by E. M. Guppy and L. Hawkes in xenocrysts, from a dyke in Iceland (1925, p. 329), or the fritting described by Tidmarsh.

VI. CORROSION OF PLAGIOCLASE PHENOCRYSTS.

Similar, but less complete, disintegration of plagioclase phenocrysts is evident in some acid dykes. The same phenomena have been noted in Rum and Ardnamurchan.

The phenocrysts split into aggregates of rectangular fragments, retaining optical continuity. Albite twinning is also, as a rule, retained. The writer considers that resorption is the only cause that has led to disintegration and has found no evidence of the co-operation of fluxion comparable with what A. G. MacGregor has described in somewhat analogous cases (1932, p. 33). The phenocrysts may easily have been in unstable surroundings, if magmatic differentiation, due to crystal settling, were in operation. In basic dykes zoning is the apparent equivalent reaction.



Text-fig. 8.—Accidental xenoliths in dykes. A, buchite; B, quartz-felspar aggregate.

VII. BIBLIOGRAPHY.

BAILEY, E. B. 1924. In "The Tertiary and Post-Tertiary Geology of Mull", *Mem. Geol. Surv.*

BOWEN, N. L. 1928. *The Evolution of the Igneous Rocks*, Princeton.

FLETT, J. S. 1909. In "The Geology of the Seaboard of Mid-Argyll (Explanation of Sheet 36)", *Mem. Geol. Surv.*

—— 1911. In "The Geology of Knapdale, Jura, and North Kintyre (Explanation of Sheet 28)", *Mem. Geol. Surv.*

—— 1930. "The Teschenite of Easter Dalmeny," Sum. Prog. for 1929, pt. iii, p. 59, *Mem. Geol. Surv.*

GUPPY, E. M., and L. HAWKES. 1925. "A Composite Dyke from Eastern Iceland," *Quart. Journ. Geol. Soc.*, lxxxi, 325.

KENNEDY, W. Q. 1931. "On Composite Lava Flows," GEOL. MAG., LXVIII, 166.

MACGREGOR, A. G. 1932. "Note on Corroded Ferromagnesian Phenocrysts," *Trans. Edin. Geol. Soc.*, xii, 329.

MAUFE, H. B. 1909. In "The Geology of the Seaboard of Mid-Argyll (Explanation of Sheet 36)", *Mem. Geol. Surv.*

THOMAS, H. H. 1924. In "The Tertiary and Post-Tertiary Geology of Mull", *Mem. Geol. Surv.*

TIDMARSH, W. G. 1932. "The Permian Lavas of Devon," *Quart. Journ. Geol. Soc.*, lxxxviii, 712.

TYRRELL, G. W. 1928. "The Geology of Arran," *Mem. Geol. Surv.*

The South Hill Lamprophyre, Jersey.

By H. G. SMITH, Queen Mary College, London.

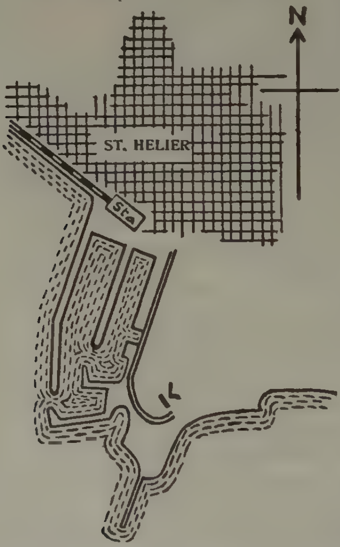
A BRIEF account of this dyke was published in 1933,[1] but since that time further studies, with assistance from Dr. A. E. Mourant and Mr. A. J. Robinson, have been made, and the results seem to be of sufficient value to justify a return to the subject.

The intrusion is 10 feet wide, has a trend N. 25° W., and is well exposed in the almost vertical face of an old granite quarry. A certain heterogeneity is obvious at a glance at the exposure. Large lenticular masses, some of them a few feet long, of dark solid rock, extend with their long axes roughly parallel to the dyke margins. These masses are embedded in a yellowish, more friable variety, which has a fissility trending in the direction of the contact. In this softer variety are to be found small harder fragments which can easily be extracted, sometimes even without the use of a hammer. On the whole the compact variety forms the central and major part of the intrusion, the friable rock forming the marginal portions, but the junction between the two is very irregular. In addition there are two narrow veins of fine-grained, reddish rock, each about 1 cm. wide, placed symmetrically in the dyke, about 3 feet from either margin and parallel to it. An attempt is here made to give an account of the several varieties of which the intrusion is composed.

The hard compact variety, constituting the lenticles, consists mainly of biotite, pale green pyroxene, and pseudomorphs after olivine, with a groundmass of fresh orthoclase. The biotite has a rich reddish-brown colour, has a tendency to idiomorphism, and exhibits zoning, usually with a dark border and light interior, but exceptions with a dark centre are not uncommon. Lenses of colourless fibrous serpentine are sometimes inserted along the cleavages, the fibres being perpendicular to the elongation of the lens. The crystals of biotite are sometimes bent, and in some cases there is a tendency to grouping in a ring. The pyroxene is idiomorphic in some cases and is often perfectly fresh, but all stages of alteration to a chloritic material are displayed. Some of these crystals have a fringe of bright green aegirine. This fringe is usually discontinuous, and contact with the diopside is perfectly sharp. The olivine pseudomorphs, preserved mainly in carbonate, are usually surrounded by crystals of biotite in such an intimate manner that the latter must be the product of a reaction between olivine and magma. An interesting mineral, barkevikite, is fairly abundant, occurring sometimes as independent crystals with typical amphibole form, cleavages, and pleochroism, this brownish-green mineral is usually closely associated with biotite. Occasionally it occurs interleaved with that mineral, lying along the cleavages, but as a rule it is plastered on the outside of the biotite and in some cases moulded upon it so as strongly to suggest that the formation of the biotite preceded that of the amphibole. The orthoclase of the groundmass is beautifully fresh, so that there is no doubt as to its identity.

---

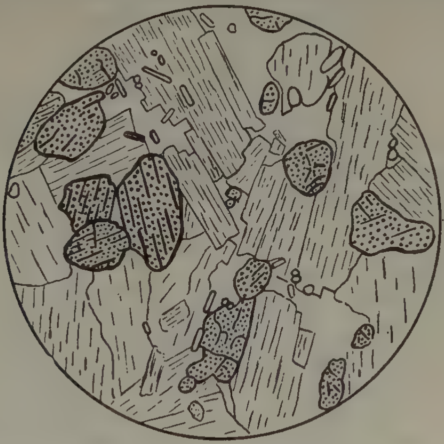
[1] H. G. Smith, *Proc. Geol. Assoc.*, xliv, 1933, 121.



Text-fig. 1.—Sketch-map showing the situation of the South Hill Lamprophyre (L), east of the Harbour. Scale 2 in. = 1 mile.

Apatite occurs included in everything and there is some calcite moulded on felspar and other minerals. A little quartz is present.

When sectioned the rock forming the fine-grained reddish veins is seen to consist largely of orthoclase in stumpy crystals, between which are calcite and quartz. There is a little biotite, and some aegirine and barkevikite. In one case the aegirine is indented by felspar, while the barkevikite, although sometimes as independent crystals, tends to mould itself on biotite. In places the silica is present as chalcedony. Where quartz and calcite are in contact the former is the earlier, and in some such examples the quartz has an outer border polarizing as an aggregate, suggesting that it has passed through the stage of tridymite. This somewhat remarkable vein is obviously consanguineous with the lamprophyre, yet it is manifestly a soda-microgranite allied to grorudite. Its presence gives rise to interesting speculations.



Text-fig. 2.—" Basic segregation." Showing diopside, biotite, apatite, and orthoclase. Magnified 22.

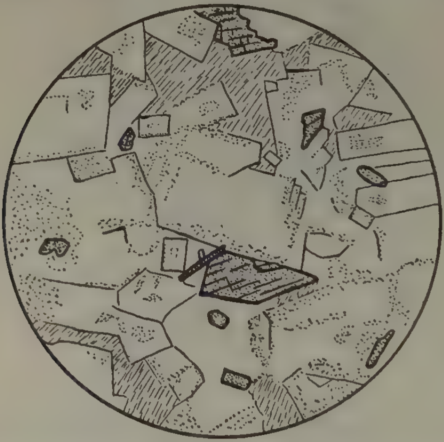
Sections through the yellowish friable rock do not show any striking differences from the more solid variety. The biotite, however, has a more bleached appearance and the felspar has become rather cloudy.

One of the fragments picked out from this soft material contains pale biotites enclosing patches of iron oxide, sometimes as lenticles along the cleavages; but the greater part of the rock is made of a granular mineral, now preserved in a mixture of calcite and quartz, but almost certainly olivine originally. Black iron oxide occurs between these grains.

Another such fragment consists almost entirely of fresh diopside and biotite, though there is a little interstitial felspar and calcite.

The pyroxene has a tendency to idiomorphism and the biotite is moulded upon it. The whole has the aspect of an ultrabasic rock.

A third fragment supplies a remarkable case. It is almost spherical and is about 2 cms. in diameter. Externally it obviously consists of biotite, with the cleavages arranged tangentially. A section through it shows little besides biotite. Towards the centre, probably because the section was not quite radial, are biotites with hexagonal outlines. There are a few crystals of diopside and barkevikite, and some slightly decomposed felspar with a radiate habit. This example is considered to be analogous to the preceding fragment, though why the globular character has been developed is not at all clear. In this connection, however, it is well to remember that in the normal lamprophyre a somewhat similar tangential arrangement of biotites on a smaller scale has been mentioned.



TEXT-FIG. 3.—Soda-microgranite. Showing aegirine, barkevikite, orthoclase, calcite, and quartz. Magnified 22.

Other examples are obviously accidental xenoliths, one of an impure sandstone and another a schistose rock. Neither has suffered any great change, and they probably represent fragments caught up at a late stage in the history of the intrusion.

Interest centres about the basic xenoliths and the soda-microgranite. It seems possible that these xenoliths represent fragments of ultrabasic rock caught up by a less basic magma and more or less made over by reaction as suggested by Dr. Bowen.[1] The obvious magma to effect this reaction is the lamprophyre. But what of the lamprophyre itself ? Maybe this is a later stage in the reaction process and represents altered xenolithic material mixed up with a portion of the magma responsible for the change. The very general parallelism of the biotites and their frequent bending suggest that intrusion was not a mere injection of liquid. The limited extent of the individual intrusions also points to difficulty of penetration. That something more acid (and alkaline) was concerned is indicated by the occurrence of the soda-microgranite. In any case, some interesting problems are raised by this Jersey lamprophyre, and they seem to demand a certain amount of consideration.

---

[1] N. L. Bowen, *Journ. Geol.*, xxx, 1922, 513–570.

Evidence of a Late Glacial Episode within the Valley of the Lower Thames.

By J. P. T. Burchell.

SINCE my last note appeared upon the series of deposits which fills the Ebbsfleet Channel of post-Early Mousterian (Levalloisian) age [1] further excavations have been undertaken this year which have resulted in the complete sequence being established. It had been observed that the Trail with "rafts" of Coombe Rock, which overlay the flood-loam of temperate facies (deposit 8),[2] sometimes contained in its upper portion "rafts" of a pale sandy brickearth; moreover, here and there, traces of this same faintly stratified brickearth occurred upon the surface of the Trail in question. In order that the true explanation of these observations might be reached, a special excavation was made at what was considered to be the most suitable spot at the site.

The results of this excavation are fourfold; they have established that :—

(1) The Trail (deposit 9) of the previous section was, in places, the product of two glacial phases and not of one as had been conjectured originally:

(2) Subsequent to the formation of the lower portion of this Trail there was formed a cailloutis, which I equate with the Ponder's End Stage, yielding a Levalloisian industry:

(3) Following this culture a spread of fluviatile brickearth of a pale sandy nature accumulated (deposit 10):

(4) At some period after the formation of deposit 10 glacial conditions returned which were responsible for the formation of some 3 feet of Coombe Rock and Trail (deposit 11), the equivalent, in places, of the upper portion of deposit 9.

The surface soil now becomes deposit 12 in place of deposit 10 as heretofore. Professor P. G. H. Boswell has examined the site and is in agreement with the succession I have established. The next research to be completed is that which will reveal the relationship of these deposits of the "50-ft. channel" to those of the low level series and to the Upper Palaeolithic horizons. In this connection it may perhaps be mentioned that the base of the uppermost brickearth (deposit 10) drops from 50 feet above O.D. to 5 feet below O.D. within the short distance of a fraction over a quarter of a mile.

---

[1] Burchell, J. P. T., "Some Pleistocene Deposits at Kirmington and Crayford," Geol. Mag., LXXII, 1935, 327–331.

[2] Burchell, J. P. T., "Evidence of a Further Glacial Episode within the Valley of the Lower Thames," *ibid.*, 1935, 90–91.

REVIEWS.

GEOLOGIE VON SPITZBERGEN, DER BÄRENINSEL, DES KÖNIG KARL- UND FRANZ-JOSEPH-LANDES. By HANS FREBOLD. Borntraeger: Berlin, 1935. pp. x + 195, with 81 text figs. and 8 plates. Price RM. 21 (geb.).

THIS is another of the series "Geologie der Erde". For the archipelagos of Spitsbergen and Franz Josef Land it performs the same function as Nordenskiöld's contribution to the *Handbuch der Regionalen Geologie* (1921) and Nathorst's classical paper in the *Bulletin* of the Geological Institute of Upsala (1910). Both these well-known general sources have become out-of-date owing to the phenomenal activity of geologists in these regions since the war. Prominent among them has been Frebold himself who has made important contributions to the *Skrifter om Svalbard og Ishavet* and *Meddelelser om Grönland*. A comprehensive review and compilation of post-war work is therefore welcome at the present juncture, but, since the spate of geological literature on the region is still flowing, the book has been written at a difficult time. A few years ago we were content to suggest, very tentatively, certain correlations between the formations of Spitsbergen and Bear Island; now we have entered an era of correlation between the rocks of Spitsbergen and Greenland, which makes very interesting reading in the present volume, since its preparation synchronized with Kulling's important discovery of fossiliferous Hecla Hoek strata in North-East Land. The correlation of pre-Downtonian rocks over long distances can be undertaken on a fairly sound basis. The older Palaeozoic geosyncline of this sector of the polar basin, the Caledonian orogeny, faulting, denudation, and younger Palaeozoic sedimentation are assuming defined places in the linking not only of Spitsbergen and Greenland, but of Old and New World geology, and the next decade will no doubt see profound developments. Already correlations are suggested in this book between places as remote from one another as Ellesmere Land and Novaja Zemblja.

In this volume, also, the Mesozoic strata receive a proper share of attention, while the accumulating knowledge of the Tertiary beds of the West Spitsbergen coal areas is given space proportionate to the other chapters. The Quaternary receives detailed consideration, but the author does not become involved in pure glaciology.

A long list of references enables the reader to obtain full detail in those sections that are limited in an attempt to keep a balance of printing space allotted to Systems.

Many of the uniformly excellent photographs are by Frebold, most of the text figures are new or from recent publications: a special feature of the illustrations is the inclusion of an appreciable number of long cross-sections, showing structure and mutual relations either proved or as at present inferred; some of them are supported by panoramic plates. Up-to-date geological maps of the Spitsbergen archipelago and Bear Island are provided, with some local maps. Finally, mention should be made of the generous use of tables to illustrate stratigraphical successions, thicknesses, lateral changes of facies over long distances; much obscurity is thereby avoided. Recent authors' publications are quoted *in extenso.*

To conclude, then, one may justly say that Frebold's volume is clear and concise, and the text is well illustrated. It would have been easy to over-emphasize some issues and ignore others; one might have welcomed more space for some problems which in earlier publications have received a wealth of attention. The book provides a most useful statement of fact and development at a time of rapid progress. Above all, in the reviewer's opinion, it marks a stage in the recognition of the long-sought associations with northern Europe on the one hand, Greenland on the other, with suggestions that look yet farther afield. A second edition will be needed in a few years; meanwhile the first will be of great service, and its author is to be congratulated.

K. S. S.

AN UNDISCOVERED COALFIELD. By H. A. BAKER. Reprinted from *The Iron and Coal Trades Review,* 13th, 20th, and 27th September, 1935. Price 1*s.* 6*d.*

THIS very interesting paper sets forth the results of many years careful work on the underground structure of the Kent coalfield and the region to the north of it, as well as on the relations of this area to the known structure of the coalfields of England and the northernmost part of France. It should be mentioned that the author appears to have had access to several important unpublished records.

It may be said at the outset that the idea of a Charnoid trend as a dominating feature of the old Palaeozoic plateau is given up; in this connection there seems to be some slight confusion as to what different writers meant by their use of the term "Charnian axis". A few words may be quoted with slight condensation but no change of meaning: "A study of the geological map of Europe . . . shows how wide of the mark one was when attempting to elucidate the deep-seated geological structure by reference to an extension of the Charnian axis, an ancient axis of uplift, subject to posthumous movements, conceived of as being very definite in its N.W.–S.E. alignment, but as affecting a belt of country of indefinite breadth and extending S.E. from Charnwood." This may have been Dr. Baker's earlier conception, but it was not that of others. The present writer went so far as to calculate the wave-length, above 20 miles, of the series of parallel folds over a wide area in the southern Midlands having a Charnoid direction, and it was the effect of all these parallel folds taken together that were supposed to be the controlling influence. It is difficult to see how an axis starting from a single point, so to speak, could affect a belt of country of indefinite breadth. It may be mentioned that Dr. Baker's own map in the paper under review, shows a very definite Charnoid anticline in Kent.

The principal subject of the paper is an endeavour to show the existence under Sheppey, the Thames Estuary, and S.E. Essex of another coalfield analogous to the known one in Kent. From a careful consideration of all the available evidence the author has been able to construct a section showing the supposed relation of the two fields, and, although he does not say so, the result shows a striking similarity to the well-known relationship of the coalfields of Dinant and Namur. Incidentally it is brought out that in at least one instance in Kent, at the Chislet colliery, the succession of Coal-measures actually now being worked is inverted: this is in no way surprising, but is only what any one who has studied the subject seriously would expect, by analogy with Belgium, France, and the Mendips.

Another very important point is the suggested identification of the Mansfield Marine Bed at Tilmanstone Colliery. Dr. Baker believes that there is room below it for the Barnsley Top Hard seam, which may indeed be represented there by a seam 4 ft. 6 in. thick at − 3,138 ft. O.D.

The author states that he has not consulted any other geologists, which perhaps accounts in part for the scarcity of references, but one would at any rate have expected some mention of Sir Aubrey Strahan's Presidential Address to the Geological Society in 1913, which is a classic in underground geology, and deals especially with the very same area.

R. H. R.

Tectonic Essays, Mainly Alpine. By E. B. Bailey. pp. xii + 200, with 49 text-figs. and 5 pls. Oxford: Clarendon Press, 1935. Price 12*s*. 6*d*.

"THE two words tectonics and architecture, are derived from the same Greek root. Tectonics may be defined, for geological purposes, as the architecture of the earth's crust. Man, in ignorance rather than presumption, has reserved the more pretentious title for the product of his own brain and hands." This is the opening thought in a stimulating and interesting book covering a wide range of Alpine controversy; and it calls to the mind of the reviewer the old argument between a doctor, a geologist, and a politician on the relative antiquity of their respective professions. The doctor claimed as a surgical operation the construction of Eve out of a rib from Adam; the geologist claimed as his province the creation of the world out of chaos; but the politician claimed patent rights for his profession over the original chaos.

Professor Bailey has achieved no small measure of fame as a controversialist in his own particular sphere and it is not surprising that, in his researches over a wider field, he has paid particular attention to the great controversies of the past. We are first introduced to Werner's three-fold classification of the rocks of the world into crystalline rocks, chemical precipitates from the "Primitive" ocean, steep strata of the "Transition" period, and finally the flat rocks. Below the Kupfer-schiefer of Saxony and forming the base of the flat rocks was the *Aelter rother Sandstein* or *Rothe tode Liegende*, and hence, through an interesting error in correlation, our Old Red Sandstone. From this thought we are taken over to the unfortunate confusion introduced into tectonic nomenclature by Marcel Bertrand's choice of the term Hercynian to denote the east–west mountain system of Northern Europe, whereas to German geologists *herzinisch* structures are parallel to the north-west–south-east trend of the Harz mountains.

The next chapter gives the Chronology of Tectonic Discovery in summary form; then, after a short introduction to the main structural units of Switzerland, follows a detailed account of the history of the solution of the Glarus riddle. The development of our knowledge of the Prealps is then described up to the present stage where, by accepting a standard nomenclature for the various nappes, we are inclined to hypnotize ourselves into believing that we really understand their structure. Unfortunately the author attempts very little original criticism of the material which he describes and one cannot help wishing for more. The Klippe Nappe and the mechanism involved in its formation, for example, cannot be understood by merely accepting the name, and it still remains as one of the most difficult of the Alpine problems.

The hesitation, or sometimes blank refusal, on the part of some British geologists to accept many of the Alpine "giraffes" is perhaps understandable, if regrettable. Murchison's staunch unbelief is described when "on being shown granite actually embedded in the Flysch he replied that the apparent fragments were really geodes, concretions and bands, formed contemporaneously with the surrounding sediment. Faced with a detached monster of the same granitic material, measuring 105 × 90 × 45 feet, he attributed it without hesitation to the superficial erratic formation so well known throughout the Alps".

In dealing with the Mesozoic age of the crystalline schists of the Pennine Alps British disbelief is again much to the fore, and

Bonney is quoted as referring in 1899 to the "fog which arose from Burlington House last September".

The Hohe Tauern forms the easterly limit of the author's historical researches, and from here we are taken back westward to Provence which is dealt with as a series of abstracts of Marcel Bertrand's memoirs.

Such criticism of this interesting and refreshing book as one may feel is already discounted in the preface. The essays are obviously not as complete as might have been wished and the references to many of the topics dealt with have not been brought up-to-date. They leave one asking for more, and in particular one would have wished that some spice had been thrown into present-day Alpine controversy, of which a sufficiency remains, by the author's own inquiring mind. But the fact that they might have been better does not mean that they are not very good as we are given them.

G. M. L.

GEOLOGIE DER ERDE: GEOLOGIE VON GRÖNLAND. By LAUGE KOCH. pp. viii + 159, with 12 text-figs. Berlin: Gebrüder Borntraeger, 1935. Price RM. 14.80 (geb.).

A COMPREHENSIVE treatise on the geology of Greenland is welcome, for of recent years a rich harvest of new facts has been gathered from this vast region, where the majority of the more important geological subdivisions are now known. A group of eleven specialists in Greenland geology have already directed attention[1] to several inaccuracies and mistakes in Koch's book, and their full, if not entirely unbiassed, criticism disposes of the need of a lengthy review here, but a few points may be stressed. Pre-Cambrian metamorphic rocks constitute a large part of Greenland but hardly any information is given on this subject. There is also small justification for the erection of yet another name, *Grönlandium*, for the series of late pre-Cambrian sediments; insufficient evidence is provided why they should not be named according to existing terms. On p. 151, fig. 12 shows the north Atlantic geosynclinal system, a drawing largely founded upon the distribution of the Caledonides; it is gratifying that Koch recognizes the East Greenland Caledonides as possible extensions of those of the Appalachians, but his correlation of the structures of the north-west Highlands, Scandinavia, and Spitsbergen is open to doubt, because each apparently represents a different frontal margin.

It should be remembered in the face of adverse criticism that Koch has sifted out much reliable information from what are sometimes extremely involved publications, and no one has done so much, or is more conversant with, exploration in Greenland. Unhappily, the task required the assistance of others more deeply versed in geological principles.

W. F. W.

---

[1] *Medd. fra Dansk Geol. Foren.*, vol. 8, pt. 5, 1935.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIII.

No. III.—MARCH, 1936.

ORIGINAL ARTICLES.

The Tectonics of the Purbeck and Ridgeway Faults in Dorset.

By W. J. Arkell, University Museum, Oxford.

(Concluded from p. 73.)

5. The Ridgeway Fault.

(a) *General.*

THE Ridgeway Fault may begin along the north margin of the Chaldon Anticline as mapped by Bristow (1855), but its existence there was doubted by Strahan. From the " bridge " at Holworth it certainly continues along the north margin of the Poxwell-Sutton Poyntz Anticline to Greenhill. Here it turns a double corner, the exact nature of which is problematical, and runs thence obliquely across and later along and parallel to the north limb of the Upwey Syncline to a point ½ mile west of Portisham, where it dies out in Kimeridge Clay. The total length from near Chaldon is 13 miles.

The relations of the rocks along this fault are complicated by the intra-Cretaceous folding and unconformity, and good sections are scarce. The general effect of the fault is to throw Chalk and Upper Greensand to the north of it against various members of the Jurassic and Wealden Beds to the south. The Chalk adjacent to the fault has been much shattered, but wherever the bedding can be made out it dips steeply northwards, away from the fracture, at angles varying from 25 to 60° and in one place 85°, but usually 40 to 45°. A short distance away the dip flattens out to a gentle fall of 5 to 15° under the Hampshire Basin.

The Jurassic and Wealden rocks on the south of the fault vary greatly in dip according to the intra-Cretaceous structures dissected by it. Along the north side of the intra-Cretaceous Poxwell-Sutton Poyntz Anticline the Portland and Purbeck Beds dip north into the faults at angles of 45 to 70°. Here the Tertiary fault has coincided with the north limb of the intra-Cretaceous anticline. The same relations are seen north-east and north of The Knoll, between Bincombe and Ridgeway, but here the fault runs along the south limb of the intra-Cretaceous Upwey Syncline. At the Ridgeway tunnel it cuts obliquely across the axis of the syncline and thence to Portisham follows its northern limb, with the result that the Purbeck and Portland Beds dip south, away from the fault. The same relations recur at the opposite end, in the Chaldon Anticline (see Text-fig. 5).

The rocks on the south of the fault usually range from the Kimeridge Clay to the Wealden, but at Bincombe village and Ridgeway railway-cutting complications are introduced by the presence of two small wedge-shaped inliers of Oxford Clay, one of them with Cornbrash and Forest Marble. These will be considered later, for they present problems of their own. Leaving them aside for the moment and viewing the fault as a whole, it is clear that, wherever it can be detected at all, along its whole length (including the inliers), its essential effect is to throw Chalk on the north side on to the same level as and below Jurassics on the south. Any explanation of the structures must first account for this primary effect; but when the question is examined in detail, it becomes apparent that it is not possible to provide a satisfactory explanation simply by normal faulting, as supposed by Bristow (1852).

(*b*) *Previous Interpretations.*

The first to recognize the peculiar features of the Ridgeway Fault were Buckland and de la Beche (1836, pp. 35–6 and pl. ii). They called it an "upcast fault", "elevating, on its south side, into contact with the escarpment of the chalk, strata that would otherwise have dipped beneath it." According to them "the strata have been raised on both sides of the fault, but raised unequally . . . the Portland Stone has been elevated from its original position, relatively, though not absolutely, much higher than the chalk." They showed the fault-plane as in some places perpendicular (their pl. ii, figs. 2, 4, 5) and in others as hading gently to the south (their pl. ii, figs. 1, 3). Their interpretation, therefore, in modern terminology amounted to a reversed fault upthrown on the south side.

Strahan ignored this earlier interpretation and adopted a more complicated one by analogy with Purbeck. According to him the Ridgeway Fault was an overthrust from the north, and the upturned chalk on the north side was the lower limb of the "S" produced by an earlier Tertiary fold like that of Purbeck. To explain the inliers at Bincombe and Ridgeway he supposed a thrust sheet to have travelled for at least $\frac{1}{2}$ mile from the north, along a flat-lying plane lubricated by "the greasiness of the Oxford Clay" (Strahan, p. 227). Thus for the first time tectonics with an Alpine flavour were introduced into England, and the interpretation appears to have remained unquestioned for forty years until this day. Since, however, as explained above, the analogy between the Ridgeway and Purbeck disturbances is not close, and in any case does not point to thrusting to the south but rather to normal faulting with downthrow to the north, it is desirable to examine the Ridgeway Fault on its own merits. It is all the more desirable because the fault-plane, as mapped by Strahan himself, and as sectioned in the Ridgeway railway-cutting, is approximately if not perfectly vertical; a fact irreconcilable with flat-lying thrusts.

The theory put forward by Weston (1852) that the Jurassic beds thin out and disappear along the fault need not detain us. Fisher's idea (1896) of a reversed fault upthrown on the north side does not explain any of the problems, for he postulates it as lying within the Chalk, to the north of the actual line of anomalies.

(c) *Observations of the effects of the fault on the rocks in contact with it, its relation to folds, and its hade.*

The most constant and most striking feature connected with the Ridgeway Fault is the fact that along its whole length the Chalk immediately adjacent to it is violently shattered and traversed by planes of slickensiding in all directions. The bedding is often wholly obliterated, but where it can be made out the dip, as stated, is always steeply north in a belt a few hundred feet wide adjoining the fault, beyond which it flattens out and may even turn gently round to the south. The shattered and tilted chalk is often traversed by minor thrust-planes, which undulate but in general all hade to the south, indicating small overthrusts from south to north. The width of the shattered belt varies widely from place to place, and the upward turn is sometimes very sharp.

The nearest chalk pit to the fault is at Portisham, 200 yards north-west of the church, where 8 feet of chalk can be seen within 14 yards of the line of the fault as marked on Strahan's 6 in. field maps.[1] The rock is so shattered and cut up by slickensiding that it becomes in places a breccia. No bedding whatever is discernible.

Intense shattering and total obliteration of bedding extends to 200 yards from the fault in a big chalk pit in the side of a dry valley 700 yards north-north-east of Friar Waddon. Here a 30–40 ft. section can be seen. A little farther west, on Corton Down, 700 yards north-north-west of Corton Barn, an old limekiln pit still provides a small section which proves that intense shattering and slickensiding here extend to over 400 yards from the fault. I was unable to determine any definite dip in either of these sections. On the other hand, near Upwey, in three chalk pits near the pumping station, on either side of the Bridport road, the stratification can still be made out by lines of flints, in spite of much shattering. The largest pit, on the west side of the valley, probably lies within 60 yards of the fault. As Strahan noted on his field map, and as can still be seen, the chalk curves up sharply from a dip of 15° north to 45° north in a distance of 15 yards as it approaches the fault (Text-fig. 6A).

---

[1] The pit is not marked on his map or referred to and so probably was not in existence at the time of the survey.

In the Ridgeway cutting, near the tunnel mouth, the dip of the Chalk adjacent to the fault was measured as 85° north, and the basal Eocene strata on Bincombe Down are also tilted to or nearly to the vertical at their southern edge but rapidly flatten out northwards (Fisher, 1896). At Bincombe village a chalk pit shows that the dip about 200 feet from the fault is 45° north.

At Greenhill Barton a small pit, now nearly obliterated, must be almost as close to the fault as that at Portisham. Strahan noted on his field map that it contained "a thrust dipping south at 40° in nodular chalk, much shattered". Another pit containing "numerous small overthrusts" was noted by Strahan at Moigns Down Barn (1898, p. 222) and is still open. Similar steep northerly dip and overthrusting towards the north are clearly shown in a new pit beside the road to Ringstead, close to the inferred line of the Ringstead Fault.

Now it is an essential part of Strahan's theory that this steep northerly dip of the Chalk along the line of fault is the lower curve of the steep limb of a large asymmetric anticline like that of Purbeck. The theory necessarily involves assuming that when the Chalk, which was not only bent but lowered by the flexuring, was subsequently thrust back upwards and southwards, the fault-plane everywhere exactly followed the curved strata and the curve was retained intact. The improbabilities involved in these assumptions have already been pointed out in connection with Ballard Point. Moreover, although the fault and curved chalk run approximately parallel to the Weymouth (= Broadway) Anticline, Strahan (1898, p. 229, and 1895, p. 551) emphatically asserted that this anticline was of intra-Cretaceous and not Tertiary age.[1]

There is no evidence that there was any minor Tertiary anticline running continuously along the north side of the main Weymouth axis, except in the east, in the Chaldon Anticline. This is, however, too flat a structure to be responsible for such steep dips in the Chalk as have been measured along its northern flank and farther west. If there was any Tertiary revival of the Poxwell-Sutton Poyntz Anticline the posthumous Tertiary anticline can have been only a flat saddle, for the intra-Cretaceous structure was already deeply denuded before the Albian transgression. This is shown by the fact that at White Horse Hill the Albian apparently rests on the core rock, Kimeridge Clay.

---

[1] It seems unlikely that there was no upheaval of the Weymouth Anticline in the Tertiary, since its axis falls precisely into line with the axis of the Purbeck Anticline, of which the amplitude and intensity off White Nothe seem far too great for it to have died out altogether in Weymouth Bay.

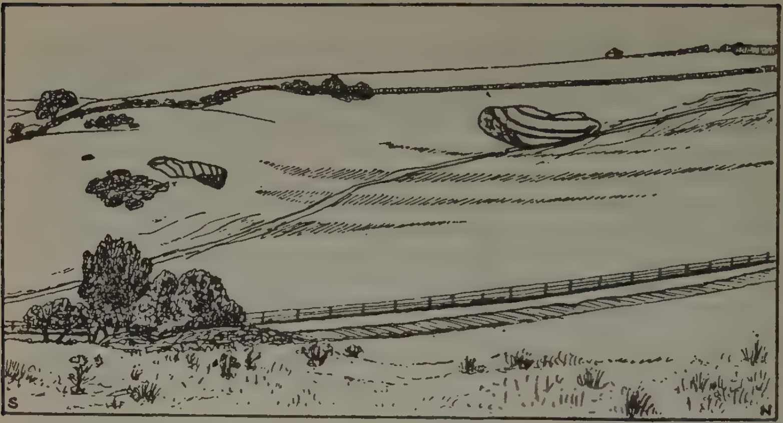
That the Upwey Syncline is wholly of intra-Cretaceous age and did not have a sharp anticline superimposed on it in the Tertiary is, I think, clearly demonstrated at its eastern end, between Upwey and Bincombe. Here the syncline passes obliquely under the Albian and Chalk, and there is no sign of any folding of the transgressive Cretaceous rocks above it, either anticlinal or synclinal. A valuable analogue is provided by the Litton Cheney Syncline, about 3 miles north of Abbotsbury. The dips are about the same as in the Upwey Syncline, the width is comparable, the axis is parallel, and the rocks are the same as in the Upwey Syncline at Abbotsbury—Kimeridge Clay and Corallian Beds. Along the north side of the Litton Cheney Syncline runs a Tertiary east–west fault which throws down Chalk against the Jurassics (and it is interesting to notice that Strahan (1898, p. 228) interpreted this analogue of the Ridgeway Fault as a normal fault). But the great value of the Litton Cheney Syncline for the present problem is that towards the east it disappears abruptly under transgressive Albian and Chalk, which strike north–south at right angles across it and are arched up over it in a gentle anticline comparable with that at Chaldon. There are here no such steep dips in the Chalk as are found along the Ridgeway Fault.

Evidence of the effects of the fault in the Jurassic rocks on the south or upthrow side is scarcer, owing to the rarity of exposures, and what there is is more difficult to interpret owing to the steep and variable dips already imposed during the intra-Cretaceous folding. Some illuminating sections can be seen, however, in the valley followed by the Bridport road north of Upwey. On the east side of the valley south of the pumping station, near the chalk pits already mentioned, a large quarry shows Lower Purbeck Beds dipping at 30 to 50° in a direction south 30° west, in the northern limb of the intra-Cretaceous Upwey Syncline. At the north extremity of the quarry, within perhaps 20 yards of the Ridgeway Fault, the beds suddenly flatten to 20° (Text-fig. 6B). The section is continued towards the fault by a second and smaller quarry in the same beds on the opposite side of the valley.[1] It lies within a few yards of the fault and 75 yards south of the large chalk pit referred to on p. 99 (Text-fig. 6A). About 21½ feet of Lower Purbeck *Cypris* Freestone and shales are exposed, dipping at 60 to 65° north, 30° east, in the south end of the pit, and gradually increasing in dip to 80 to 85° at the north end. At the south end the strata are in addition bent into a sharp elbow, as shown in Text-fig. 6A. The reversal of dip towards and close to the fault as shown in these two quarries is so abrupt that it is almost certainly due to drag.

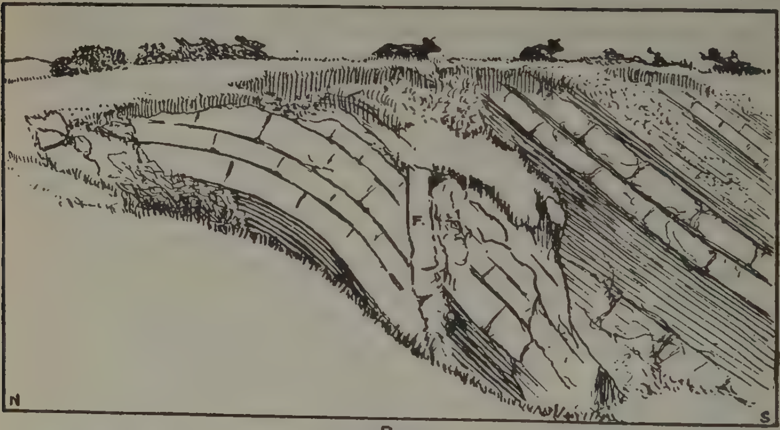
The larger of the two quarries, that on the east side of the valley,

---

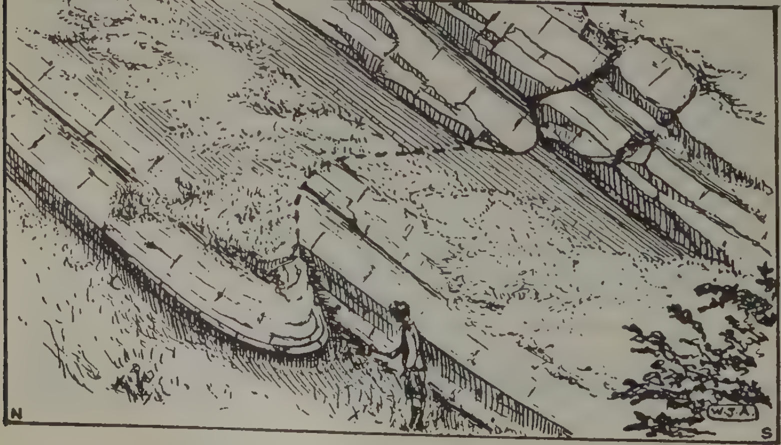
[1] This quarry is not marked on Strahan's field map of 1890, but was already disused in 1905, according to the farmer. I had it cleared of debris and brambles in August, 1935.



A



B



C

shows in addition two minor faults precisely parallel with the main fault near by. One is a simple straight fault with a hade of 10° south, 30° west, but having an *upthrow* of 2 feet; in other words it is a reversed fault, upthrown on the south side (Text-fig. 6B).

The other small fault is difficult to interpret, but it too shows distinct upthrow phenomena along at least part of its course. The end of a faulted band of limestone is bent round to form half a circle and then overthrust towards the north for about 4 feet, as shown in Text-fig. 6C. Higher up, however, the fault-plane turns over to the south and the effect simulates that of a normal fault, with downthrow to the north. It seems that the anomalous effects were produced by an exceedingly irregular fault-plane with reversed movement, and possibly also a tendency to local torsion or hingeing. A similarly irregular junction was traced by Fisher between the Wealden Shales and Oxford Clay in the Ridgeway cutting (in Stuart, 1889, facing p. 69).

The hade of the main Ridgeway Fault itself, if any, still remains to be conclusively determined. It seems certain that the fault-plane is everywhere very nearly if not quite vertical, at least where it approaches the surface. At the only place where a cross-section has been seen, in the Ridgeway railway-cutting, Weston drew it as vertical and Fisher drew it with a hade of 17° to the south (drawings reproduced in Strahan, 1898, pp. 224, 225). This evidence, so far as it goes, is at least totally incompatible with Strahan's theory of a flat-lying thrust from the north. It is not known on what evidence Buckland and de la Beche (1836, pl. ii, figs. 1, 3) represented the hade as gently but definitely south both at Poxwell and on the east of the Bridport road north of Upwey, or whether they had any evidence. At Moigns Down and Sutton Poyntz they showed it as vertical (1836, pl. ii, figs. 2, 4, 5). Strahan's 6 in. maps and my own examination of the ground lead to the conclusion that if there is any hade in either direction it is almost inappreciable along the whole course of the fault. Numerous valleys have been cut across it by denuding agencies, but the trace does not seem to tongue either up them or down them.

TEXT-FIG. 6.—The Ridgeway Fault at Upwey and parallel minor faults.

A.—View of two quarries referred to on p. 99, looking west. The left-hand quarry shows Lower Purbeck beds dragged over north into the fault, their normal dip left of the quarry being 40 to 50° in the opposite direction. The right-hand quarry shows Chalk and bands of flint dipping as shown. The stratification in both quarries accentuated diagrammatically. The fault runs between the quarries and approximately under the observer.

B.—Quarry in Purbeck limestones and shales on east side of valley, referred to on p. 101, showing strata beginning to be dragged over towards the fault, which lies a few yards to the left, and a small reversed fault with dyke-like fault-breccia at F.

C. Same quarry, with irregular reversed fault upthrown on south. The fault-plane is dotted where obscure, but its continuation underground is unknown. Based on photographs.

The evidence, therefore, may be summarized as follows:—

1. The plane of the Ridgeway Fault is nearly or quite vertical, but there may be locally a slight southerly hade.
2. Small faults parallel to the main fault on the south side have a definite slight southerly hade and are reversed faults, upthrown on the south side.
3. The Jurassic rocks on the south side of the Ridgeway Fault show puckering and steep downward drag towards the fault.
4. The Chalk on the north side shows much shattering and a sharp upward tilt towards the fault, and the uptilted portion contains numerous small flat-lying overthrusts towards the north.
5. The upward tilt of the Chalk cannot be identified with any known anticline; it is closely associated with the shattering and the thrusting, and all three closely follow the fault. Hence they are probably all causally connected with the fault.

This evidence clearly points to the Ridgeway Fault having been formed under pressure rather than tension, and to its being a reversed fault upthrown on the south side, as stated by Buckland and de la Beche over a century ago.

How much of the upward tilting of the Chalk can be ascribed to pure drag and how much to initial curvature must remain uncertain. There can be little doubt that during the Tertiary earth-pressures a sharp monoclinal flexure arose along the line of the present fault, owing to uplift of the country to the south relatively to that to the north. There is no evidence to show that it was an anticline like that of Purbeck. Rather it appears to have been merely the expression in the Chalk and Tertiaries at the surface of a deep-seated reversed fault in and below the Jurassics underneath. Eventually the Chalk fractured also, and so flexure and fault ran into one another.

The same process has been invoked by Prof. Pruvost (1922) in explanation of the contemporaneous and nearly parallel Landrethun Fault in the Boulonnais (see Text-fig. 9B, p. 115, below). He shows the hade as northward, thus making the fault a normal fault, but it is not clear that there is any evidence for this. The Hogs Back provides another but less close analogy. The strike fault which there cuts the monocline is definitely known to be reversed; but the hade to the south as portrayed by Dines and Edmunds (1927, pl. 13) is much greater than anything known along the Ridgeway Fault.

A reason for the occurrence of a reversed fault along this line in South Dorset is provided by a study of the Ridgeway and Bincombe inliers. As will be shown in Section (*e*) below, these inliers are only explicable on the assumption that the Tertiary Ridgeway Fault almost coincides with an intra-Cretaceous normal fault of almost the same strike but large opposite downthrow. The pre-Albian (Aptian ?) denudation and peneplanation which followed the early faulting removed a thick pile of Jurassic sediments from the upthrow side of the older fault, but barely touched those on the downthrow side. Consequently, at the onset of earth-pressures in the Tertiary, when the Purbeck-Weymouth Anticline was upheaved, there would have been a tendency for these inequalities to readjust themselves. The deep column of sediments on the south of the old fault would have been the first to receive the elevating impulse from below, and differential movement would have resulted, more or less along the old line of fault, but in the reverse direction.

(*d*) *The Question of the Continuity of the Fault.*

Bristow (1855) considered the Ridgeway Fault to be continuous from east of Chaldon to the Chesil Beach. Strahan thought differently. In Strahan's sketch-map (pl. vi, facing p. 221), post-Cretaceous " disturbances and faults " are marked (by thick black lines) while in the colour-printed map (Sheet 342) the faults only are marked (by white lines). By comparing these maps, and bearing in mind that where the thick black lines in pl. vi are not faults they are not axes of folds but are drawn where the chalk dips especially steeply, we find that Strahan regarded the Ridgeway Fault *sensu lato* as divided into the following sectors of different origin (from east to west) :—

1. Chaldon anticline (1½ miles). Albian and underlying Purbeck and Wealden Beds have opposite dips, due to unconformity. No fault.
2. Moigns anticline. Thrust-fault as far as Poxwell church (1½ miles) and " disturbance " for another mile. Jurassics dip steeper than Chalk.
3. White Horse Hill, north of Sutton Poyntz (1¼ miles). Neither fault nor disturbance (see also Strahan, p. 222). Jurassics dip steeper than Chalk, due to unconformity).
4. Bincombe and Ridgeway. Thrust-fault for ½ mile at Greenhill, followed by double thrust-fault for about 1¾ miles (see Section (*e*), below).
5. Upwey to ½ mile west of Portisham (5 miles). Jurassics and Wealden with opposite dip to Chalk, due to thrust-fault (the main Ridgeway Fault as marked on his pl. viii).

If we rearrange the five sectors according to the rock-relations instead of geographically, and add the Ringstead " disturbance ", it will be seen that there is inconsistency between the rock-relations and Strahan's interpretation in different sectors.

(*a*) *Chalk and Jurassics dip in opposite directions.*

Sectors.	*Strahan's interpretations.*
1. Chaldon	1. Unconformity.
5. Upwey-Portisham	5. Thrust-fault.

(*b*) *Chalk and Jurassics dip in same direction, but the Jurassics more steeply.*

2. Moigns Anticline	2. Thrust-fault.
3. White Horse Hill	3. Unconformity without "disturbance".
6. Ringstead Anticline	6. Unconformity with "disturbance".

(*c*) *Chalk and Jurassics dip in same direction, but the Chalk more steeply.*

4. Bincombe	4. Two thrust-faults.

An examination of the ground shows that in the places where Strahan attributes the discrepancy in dip wholly to the intra-Cretaceous unconformity (sectors 1, 3, 6), the ground on the south side of the Jurassic–Albian junction is lower than that on the north. The appearances are merely those of a normal Chalk escarpment overlooking a clay vale, and it would be agreed that there seems no reason to invoke faulting of any kind.

In the sectors where Strahan explains identical discrepancies in dip by faulting, however, the ground on the south side of the Jurassic-Albian junction is high relative to the chalk base on the north. In sectors 2 and 5 and at each end of 4, the Chalk has obviously been lowered to the level of the Jurassics.

Now in those places where the ground is high on the south side of the Jurassic–Albian or Jurassic–Chalk junction the rocks forming the surface consist of hard Portland or Purbeck Beds. In those places where the ground is low and there are no appearances of a fault, the surface-rock south of the Jurassic–Albian junction is a soft clay or sand (Kimeridge Clay in sectors 3 and 6, Oxford Clay in the middle of sector 4, and Wealden Beds in sector 1).

It is therefore difficult to decide whether the apparent discontinuity of the fault as inferred by Strahan is not due merely to the differing resistance of the rocks on the upthrow side, the arrangement of these rocks in turn having been determined by the pre-Albian unconformity. When chalk is faulted down against a clay, as it is against Kimeridge Clay at the mouth of the Vale of Wardour, it resists weathering longer than the clay and may remain as a high escarpment overlooking the upthrow side of the fault which denudation has reduced to a low vale. Since the appearances in the Vale of Wardour are the same as at White Horse Hill, Sutton Poyntz, and Chaldon, it cannot by any means be considered proved that the Ridgeway Fault is interrupted wherever no displacement is shown by the surface-contours. The tilting of the chalk continues past these places just as it does where the fault is obvious, but whether the shattering also continues there are not adequate sections to show.

The sudden steep plunge of the Chalk at South Down Farm on the Ringstead fold is definitely accompanied by shattering and thrusting, and so a reversed fault can in my opinion be inferred. On this point I am in agreement with Bristow's mapping (1855).

The following paradox is worth pointing out :—Where Chalk and Jurassics are on the same level Strahan introduces a fault, but a thrust-fault which has *raised the Chalk* (which must have been previously lowered by flexuring) ; but where on the very same line, as at White Horse Hill, *Chalk stands higher than the Jurassics*, and consequently might have been interpreted on his hypothesis as thrust up still higher than in the other places, he dispenses with a fault. The stages of his reasoning thus appear to have been as follows :—The obvious lowering of the Chalk in certain places demanded the introduction of a normal fault ; later, by analogy with Purbeck and to explain the Bincombe and Ridgeway inliers (to be dealt with below) he assumed it to be a thrust, at the same time forgetting the reversal of the effects involved also in the places where he had first invoked the normal faulting.

(*e*) *The Bincombe and Ridgeway Inliers.*

We now come to the most crucial points in the tectonics of the South of England.

The inlier revealed by the Ridgeway cutting consists of a dyke-like mass of Oxford Clay containing jumbled blocks of Cornbrash and showing no definite bedding, intercalated between the Chalk and the Wealden Beds.

The other inlier at Bincombe village is larger and comprises Oxford Clay, Cornbrash, and Forest Marble in regular succession, dipping gently north (at about 10°) towards the fault. These rocks are surrounded by Upper Greensand and Chalk on the north and by Kimeridge Clay and Portland Beds on the other three sides. No exposure is visible, and all that can be said on the subject has already been said by Strahan (pp. 223–7), save in so far as concerns the explanation of the phenomena.

The origin of the inliers is accounted for by Strahan by means of his well-known theory which he admits " involves much speculation " (pp. 226–7). " In it we attribute the whole of the faulting to overthrusting produced by the Ridgeway movement." " The Ridgeway fault not only belongs to the same age as the Isle of Purbeck movement, but resembles it in so many essential points, that we may infer that it also is a ' thrust ' and not a normal fault . . . the movement resembling that which took place at Ballard Point, with this difference only, that there Chalk was thrust over Chalk."

" In the Ridgeway thrust we have repeatedly seen that the fracture approximately followed the Upper Cretaceous base, sometimes exactly, but more often running a little above it. To account for the protrusion of the Oxford Clay we have only to suppose that a part of the fracture locally ran below the Upper Cretaceous base, and that some of the floor was then caught up and carried bodily southwards with the Cretaceous rocks. This seems the less improbable when the softness and 'greasiness' of the Oxford Clay are taken into account" (p. 227).

Now as a necessary condition for this hypothesis Strahan argues that Oxford Clay and Cornbrash must be brought up by intra-Cretaceous faulting or folding so as immediately to underlie the Upper Greensand beneath the Downs at a minimum distance of ½ mile to the north.[1] But if Upper Greensand can rest upon rocks so low in the Jurassic series at a distance of ½ mile to the north, as the result of pre-Albian faulting or folding, there is no *a priori* reason why it should not do so at Bincombe, as W. H. Hudleston and H. B. Woodward believed (Hudleston, 1889, p. lii; and Woodward, 1895, p. 20). As Woodward pointed out, an intra-Cretaceous pre-Albian normal fault, with a southerly downthrow, brings down Kimeridge Clay against Forest Marble at Abbotsbury, only 6 miles to the west. Strahan estimated the throw of this fault as about 600 or 700 feet (1898, p. 229). On the upthrow (north) side of it, Upper Greensand was deposited upon Forest Marble, and on the downthrow side upon Kimeridge Clay.

Now the Abbotsbury fault runs from near the Chesil Beach west about 5 to 10° north. Only ⅚ of a mile from the point where it disappears beneath the Upper Greensand, and about 100 yards to the south of the line, is the spot "about half a mile west of Portisham" where Strahan notes that the Ridgeway Fault begins. The Ridgeway Fault carries on precisely the line of the Abbotsbury Fault, and it starts at once its characteristic effects of throwing down steeply-dipping Chalk to the north against Kimeridge Clay and Portland and Purbeck Beds, regardless of the structures in the older rocks. (See Text-fig. 5, facing p. 73.)

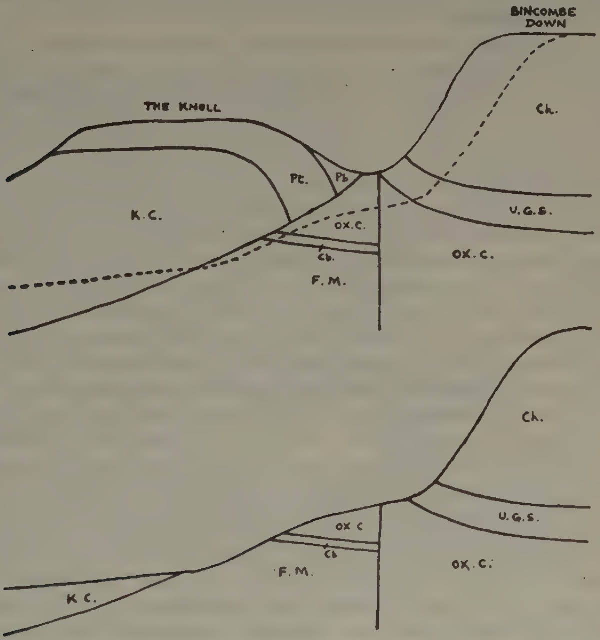
Since the Ridgeway Fault about Portisham, although following so nearly the line of the Abbotsbury Fault with opposite downthrow, runs 100 yards to the south of it, the effects of the older fault are masked at the surface. But there can be no doubt that if a boring were sunk through the Chalk more than about 100 yards north of the Tertiary fault about Portisham it would pass from Upper Greensand into Forest Marble or Oxford Clay.

We only have to assume the same parallelism of the two faults to continue for about 6 miles to Upwey and Bincombe for an adequate explanation of the Ridgeway and Bincombe inliers. Hudleston (1889) already accepted the likelihood of two such faults approximately coinciding along one line of weakness, but neither he nor Strahan seems to have realized the full significance of the proved parallelism and approximate coincidence of the two faults about Abbotsbury and Portisham.

At Upwey the two faults appear to cross, and thence eastward they gradually diverge a little in the opposite direction, the Tertiary fault to the north and the intra-Cretaceous fault to the south, so that a wedge of older rocks appears between them. The outcropping of this wedge at the surface, and especially the sudden widening at Bincombe, can be purely the effect of erosion, possibly in turn accelerated by a flattening of the hade of the older fault (Text-fig. 7).

---

[1] The Upper Greensand definitely rests on Oxford Clay 3 miles to the north of the Ridgeway Fault near Little Bredy. (See map, Text-fig. 5, facing p. 73.)



Text-fig. 7.—Diagrammatic sections (south-west–north-east) across the Abbotsbury and Ridgeway Faults, ½ mile west of Bincombe (above) and at Bincombe village (below), to illustrate the principle of the interpretation by the reversed-faulting hypothesis. The broken line in the upper figure represents the land-surface along the line of section shown in the lower figure, where erosion has gone deeper. Abbreviations: Ch. = Chalk, U.G.S. = Upper Greensand, Pb. = Purbeck Beds, Pt. = Portland Beds, K.C. = Kimeridge Clay, OX.C. = Oxford Clay, Cb. = Cornbrash, F.M. = Forest Marble. Not to scale.

East of the Bincombe inlier the older fault either dies out or is shifted north under the downs again by a north–south or north-east–south-west cross-fault of pre-Albian date, downthrowing east, like that which begins the Portland outcrop so abruptly north-east of Sutton Poyntz, and those which similarly affect the Portland and Purbeck Beds beneath the Gault under Holworth House in Ringstead Bay. It is noteworthy that the postulated cross-fault here coincides with a Tertiary fault of opposite downthrow and otherwise unaccountable trend, which " takes a bite as it were out of the

Chalk and Greensand outcrops " as described by Strahan (p. 222). This is the last that is seen of the Abbotsbury intra-Cretaceous fault.

The explanation here presented of the Ridgeway and Bincombe inliers is consistent and involves nothing improbable, and in many walks over the ground I have detected nothing contradictory to it. The same cannot be said for Strahan's picture of a great flat-lying southward thrust.

If one stands on the steeply-plunging Portland Stone to the east or west of Bincombe and looks down on the village, the Oxford Clay to Forest Marble inlier is seen to form low ground, 100 feet and more below the level of the Portland Stone on either side. If it be a " Schuppen " or wedge thrust out beneath the Upper Greensand southwards, the thrust-plane beneath it must have an extraordinary shape. Since the high Portland Beds on either side have not been thrust, there must be a sharp downward bend in the thrust-plane, at least 250 feet deep and only about 500 yards wide, filled up with the Oxford Clay and Forest Marble and Cornbrash (Fig. 7).

Strahan talks of " the almost impossible system of faulting by which it was sought to account for the Bincombe inlier on the original map " (p. 227), but he makes no apology for these equally " impossible " misshapings of the thrust-plane necessarily implied in his own explanation.

Let us now examine Strahan's criticisms of the normal-faulting hypothesis. He states (p. 226) " to account for the Bincombe inlier by any system of normal faulting we have to suppose that a pyramidal mass of Oxford Clay, Cornbrash, and Forest Marble was pushed up a distance of about 1,900 feet through but little disturbed Kimeridge Clay, a most improbable structure." This statement may be answered as follows: In the first place, it is unnecessary to suppose that the earlier rocks have been " pushed up " and such a conception forms no part of the hypothesis; in the second place the throw of the fault, for reasons discussed below, may well be a thousand feet less than the figure named by Strahan; in the third place, even if the older rocks form a " pyramidal mass " now (in cross section only), they certainly did not at the time the original faulting occurred, their present shape being imposed on them *ex hypothesi* by the Tertiary faulting nearly cutting the earlier.

The idea of a " pyramidal mass ", suggested perhaps by Bristow's original mapping on the Old Series Survey map (Sheet 17), is not at all necessary for the normal- or reversed-faulting hypothesis, and the square enclosed by faults as shown by Bristow gives a misleading impression. According to the hypothesis here advocated, as explained above, the Bincombe and Ridgeway inliers are not isolated masses but only the visible portions, bared by chance erosion, of a long east–west wedge of older rocks brought out from beneath the Chalk and Greensand east of Upwey by the scissoring across of the two faults of different dates and opposite throw. This wedge was merely sliced off from the edge of a much larger block which extends under the Downs to the north and eastward to the sea at Abbotsbury.

Strahan's principal criticism relates to the magnitude of the throw of the faults involved: "a fault of anything like this size is unknown in the Secondary Rocks of the South of England" (Strahan, p. 226). Before examining what the amount of the throw really is, I cannot pass over this remark without commenting that an overthrust against the steep limb of a monocline, such as is postulated by Strahan as an alternative, is quite unparalleled in the Secondary Rocks of the whole British Isles, or even North-west Europe. I doubt if a parallel could be found anywhere in the world.

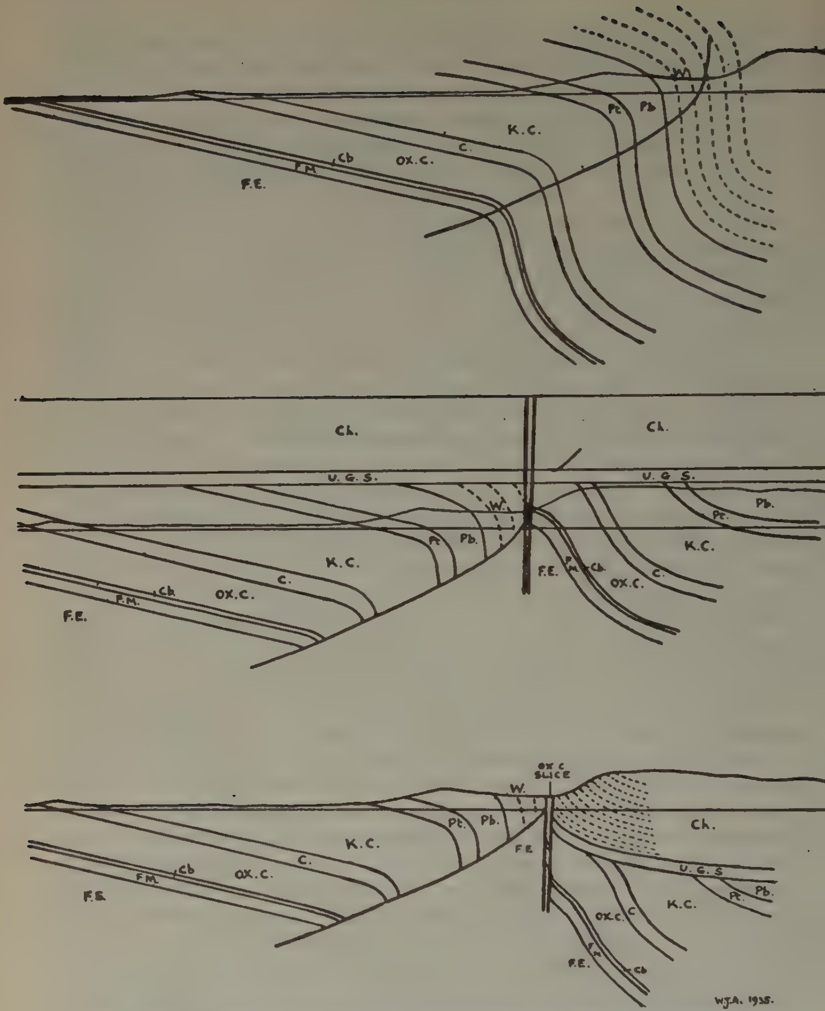
Strahan's method of estimating the throw is to add up the thicknesses of all the formations that should intervene between the Oxford Clay or Cornbrash and Middle Wealden, and he concludes that the throw must have been about 2,000 feet.

This result is a fallacy. The intra-Cretaceous fault, which is a strike fault, hereabouts cuts the Upper Jurassic and Wealden Beds along a line where they are highly inclined in the steep southern limb of the intra-Cretaceous Upwey Syncline. Between Bincombe and the Ridgeway cutting Strahan marks dips of up to 70° north in the Portland Beds. The Wealden Beds in contact with Oxford Clay in the cutting are shown as vertical, and below ground the earlier rocks must turn over too. The fault-plane, although nearly or quite vertical according to the drawings of the railway-cutting section, presumably turns round to a southward hade underground (as shown in Text-fig. 8). At Bincombe village (Text-fig. 7) it certainly does so, in order to produce the much larger exposure of older rocks below it, and an examination of the western end of the fault shows that it curves southward as the ground falls from the heights below the Greensand escarpment to the Chesil Beach, thus indicating a southerly hade there also. In this respect the railway cutting section is misleading for both of the faults visible there are Tertiary, as will be shown below. Hence the conditions are ideal for a maximum shift or displacement of bed against bed with a minimum vertical throw.[1] It is possible to draw the section along the Ridgeway cutting to scale with a fault having a throw of no more than 1,200 or at most 1,500 feet (see Text-fig. 8).

Another factor may have to be allowed for, of equally intangible amount, but on this I do not insist. Since the line where the fault runs coincides with the steep and even vertical limb of the Upwey Syncline, there would have been, according to Strahan's own views, considerable diminution in the thickness of the softer strata by squeezing. Strahan did not mention this, although he himself believed that where the strata from Purbeck Beds to Upper Greensand and Chalk stand on end in the vertical limb of the Purbeck

---

[1] A fault with horizontal hade cutting vertical beds will cut out 2,000 feet of strata without any vertical throw at all.



Text-fig. 8.—Diagrammatic cross-sections along the railway north of Upwey Junction (left) through the Ridgeway cutting and tunnel, to illustrate the present structure (bottom figure) and its origin (top and middle figures) according to the normal or reversed faulting hypothesis. Top: the south limb of the Upwey Syncline with the intra-Cretaceous fault drawn in, before movement along it. Middle: after the intra-Cretaceous faulting and peneplanation, and after deposition of the Greensand and Chalk, with the Tertiary fault drawn in but not yet moved. Bottom: after the Tertiary faulting and subsequent erosion. The strata actually seen (after Weston) are approximately those above the horizontal line representing sea-level. Scale roughly 1,000 feet = 1 inch. The thinner strata exaggerated. Abbreviations as in Text-fig. 7, plus F.E. = Fuller's Earth, and W. = Wealden Beds. For clarity the topography has been kept constant relative to the left side in all the drawings.

fold at Durdle Door, and everything can be accurately measured, 1,000 feet of strata have been compressed into 250 feet (Strahan, p. 219). According to him thick masses of clay and marl, and even whole limestone bands, have been squeezed out bodily. Whether this is the real explanation of so great a diminution in thickness at Durdle Door and Lulworth remains to be proved. Bristow (1855) believed the Wealden Beds to be partly faulted out.

Strahan further stated (p. 225) that the Tertiary fault downthrowing in the opposite direction (north) must also have a large throw. This is equally incorrect. As already explained, according to the hypothesis outlined in this paper, the Upper Greensand was deposited on Oxford Clay, Cornbrash, and Forest Marble on the upthrow side of the older fault, as can be seen at Abbotsbury. Consequently a fault of quite trivial northward downthrow is all that is needed to bring Chalk against Oxford Clay (Text-fig. 8).

There is one final point which Strahan seems to have overlooked, but which may be fatal to his thrusting hypothesis. In the Ridgeway cutting, near where the two faults cross and only a dyke-like mass of jumbled Oxford Clay separates them, isolated blocks were found in the Oxford Clay. Some of the blocks were of Cornbrash, but others were aligned vertically on the side adjacent to the Chalk and according to Fisher "appeared to be nodules of Greensand" (see Fisher's diagram, reproduced in Strahan, p. 225). If the Chalk was upthrust from below, the Greensand has never been any higher relative to the opposite side of the fault than it is at present. Since it still lies below the level of the cutting (as shown by Fisher and stated by Weston, 1848, pp. 249, 251), how did the nodules of it get up into their present position as a vertical string adjacent to the face of the Chalk?

The only explanation possible on the thrusting hypothesis is to suppose that there are two thrust-planes, one below the Oxford Clay "dyke" and the other above, and that the Oxford Clay has been thrust farther than the Chalk and Greensand and has brought the fragments of Greensand up with it. On this hypothesis the Oxford Clay must have been squeezed up vertically like tooth-paste from a tube.

On the reversed-faulting hypothesis the Greensand nodules became detached from the formation as it was lowered from its original position relative to the upthrown block.

By the same argument the blocks of Cornbrash in the Oxford Clay (if they were correctly identified) prove that the intra-Cretaceous faulting carried Cornbrash at least as high as the top of the cutting, relative to the strata on the downthrow side. But since the rock at present adjacent to the Wealden and enclosing the blocks of Cornbrash is not Forest Marble or Fuller's Earth but Oxford Clay, it, the Oxford Clay, must have been lowered again by the Tertiary faulting. Hence the Oxford Clay "dyke" appears to lie between two Tertiary step faults downthrowing in the same direction, towards the north ; in other words it is a slice, detached from the main Tertiary fault block by a local dichotomy of the fault-plane.

This interpretation explains as well as Strahan's, and by a more reasonable means, the jumbled condition of the "dyke" and the admixture of blocks of Cornbrash and Greensand with fossils of the Upper Oxford Clay. The formation of such a slice is not difficult to account for in a reversed fault and was probably conditioned by the scissoring across of the Tertiary and intra-Cretaceous faults near this point. It is, in fact, only necessary to point to the small-scale step-faulting parallel with the main fault, as shown in the Purbeck Beds close to the fault at Upwey (Text-fig. 6).

The problems of the Bincombe and Ridgeway inliers could be solved by one or two comparatively inexpensive borings. If Strahan's hypothesis is right, a boring sunk through the Forest Marble at Bincombe should pass rapidly into Kimeridge Clay or Portland Sand, for the mass has no "roots", but floats upon the Upper Jurassic strata like a "klippe", bounded below by a thrust-plane. If the hypothesis here favoured is correct the boring should pass on through the Forest Marble into Fuller's Earth and, if continued deeper (which would not be necessary), into Inferior Oolite. A boring started in Portland Beds just off the inlier should, on the thrusting hypothesis, continue through the same strata for some distance and eventually enter Kimeridge Clay ; on the normal or reversed-faulting hypothesis it should pass rapidly from Portland Beds into Forest Marble or Fuller's Earth.

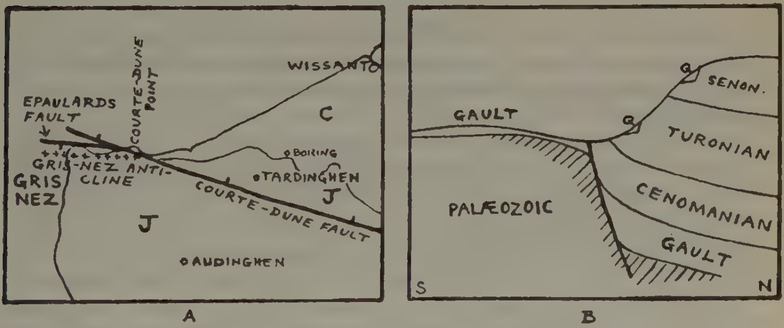
(*f*) *Some Analogues.*

The interpretation of the Ridgeway Fault advanced above depends on the approximate but not exact parallelism of two sets of faults of different ages and opposite downthrow in the same area. But it can further be said that, given these conditions, then such results as have been described must follow, for faults belonging to the two sets are bound occasionally to cross one another at a low angle.

Hence it is important to show that the necessary conditions do obtain in this area, and that they are not exceptional.

The important Tertiary east–west faults in South Dorset, of known date because they throw Chalk, are the Ridgeway, Purbeck, Litton Cheney, and Ringstead faults. (I agree with Bristow in extending the last westwards through Osmington Mills and Redcliff Point, thus making it a fault of some importance.) All these downthrow north. The known pre-Albian faults are those at Abbotsbury and Eypesmouth, and both of them downthrow south. The Abbotsbury Fault has a throw of 600–700 feet where it disappears under the Greensand and Chalk, and so presumably continues under them for at least several miles before it dies out. The Eypesmouth Fault has a throw of about the same amount, and it passes from the coast for 4 miles inland, throwing Forest Marble against Middle Lias at Watton Cliff and Oxford Clay against Upper Lias near Shipton Gorge,[1] until it disappears under the Chalk at Chilcombe Hill, where Oxford Clay is thrown against Fuller's Earth. It is here less than a mile from the Litton Cheney Fault of opposite downthrow and nearly parallel strike.

Parenthetically, it is tempting to speculate that the two east–west faults which run parallel for 5 miles from Buckland Ripers to the West Fleet, cutting only Jurassic rocks, may be of different ages (see map, Text-fig. 5, facing p. 73). They downthrow in opposite directions, leaving between them a relatively elevated tract of Forest Marble only about a ¼ mile wide. It is difficult to see how such a structure can have arisen by one act of faulting, and it seems likely, in view of what has just been said, that the fault with southerly downthrow is intra-Cretaceous and that with northerly downthrow Tertiary.



Text-fig. 9.—A: Sketch-map of the faults and folds at Cap Gris-Nez. J = Jurassic, C = Cretaceous. B: The Landrethun Fault north of La Cédule. After Pruvost, 1922, fig. 5, p. 64, and fig. 3, p. 59.

The same two systems of roughly east–west faults, the intra-Cretaceous downthrowing south and the Tertiary downthrowing north, have been recognized in the Boulonnais. Near Cap Gris-Nez the Epaulards Fault of intra-Cretaceous date and southerly downthrow strikes nearly east–west and runs parallel with an intra-Cretaceous system of folds, just as does the Abbotsbury Fault. The Tertiary Courte-Dune Fault, with northerly downthrow, scissors across the earlier fault and folds at an angle of 15 to 20°, striking inland in a direction about east 25° south (Pruvost, 1922). Cap Gris-Nez therefore provides a mirror image of what occurs along the Ridgeway Fault, but unfortunately the wedge on the upthrow side of both faults lies entirely under the sea ; and the throws involved are not so great (Text-fig. 9A). The Tertiary Landrethun Fault, which almost carries on the line of the Courte-Dune Fault (making a total length of 9½ miles) and has a downthrow in places of 330 feet north, passes laterally into a monoclinal flexure and, as already mentioned, produces an upward drag in the Chalk comparable with that along the Ridgeway Fault. (Text-fig. 9B.)

---

[1] Bristow's mapping is wrong hereabouts. The presence of Kellaways Clay near Bothenhampton seems to indicate that the Eypesmouth Fault runs farther north than he showed it, towards Shipton Gorge.

Repetition of faulting along the same or nearly the same lines with reversed direction has recently been described as characteristic of the Dent Line (Turner, 1935), and other instances could be cited from farther afield.

6. SUMMARY OF CONCLUSIONS.

1. Strahan's theory, accepted for the last forty years, that the Purbeck and Ridgeway Faults are thrust-faults from north to south, is untenable.
2. The only thrusting has been on a trivial scale from south to north. It took place along a number of ramifying, gently inclined minor thrust-planes in the Chalk of the vertical northern limb of the asymmetric Purbeck Anticline, and on a still smaller scale in the Chalk adjacent to the Ridgeway and Ringstead Faults.
3. The Purbeck Fault as sectioned at Ballard Point, Swanage, is a normal fault downthrowing north, with a rather flat-lying, undulating fault-plane. It cuts the vertical Chalk of the steep limb of the Purbeck Anticline and is therefore posterior to the folding and thrusting. It denotes a relaxation of pressure or even a substitution of pressure by tension.
4. The Purbeck Fault is much shorter than has been supposed and may extend only a few miles on each side of Ballard Point. It does not reach the sea at Bat's Head, west of Lulworth, as stated in the Survey memoir and map. The cliff there shows in reality the lower bend of the S-shaped northern limb of the Purbeck fold, which has not been appreciably faulted.
5. The easterly tilt of the south coast of England is responsible for displaying the Chalk that takes part in the lower bend of the curve near Lulworth, and the Jurassic rocks in the foreland underneath, but in the Isle of Wight only the Chalk that takes part in the upper bend of the curve, turning over and flattening southwards on to the backland.
6. The foreland of the Purbeck Anticline, as revealed in the country west of White Nothe, differs from the site of the fold and the backland in Purbeck by having experienced about a quarter of the amount of deposition between the beginning of the Portlandian and the end of the Aptian, and by having been folded, faulted, and denuded before or during the Aptian. There is consequently an unconformity below the Albian on the foreland, but no evidence for it on the backland.

7. The Ridgeway Fault is accompanied by much shattering in the Chalk, which is steeply turned up towards the fault-plane, and the upturned belt is traversed by small northerly overthrusts of flat southward hade. A section at Upwey shows marked northward drag in the Purbeck Beds on the upthrow side of the fault, and also two small reversed faults upthrown on the south side, and some contortions. All this evidence points to the Ridgeway Fault having been formed under pressure rather than tension, and to its being a reversed fault upthrown on the south side, rather than a normal fault downthrown north. It is considered likely that the fault may be a fracture along a sharp monoclinal flexure in the Chalk, the flexure in turn having resulted from a reversed fault in the rocks underneath.

8. At its western extremity the Ridgeway Fault is seen almost to coincide with the intra-Cretaceous Abbotsbury Fault, a normal fault of identical trend downthrowing south about 600–700 feet, with a southerly hade. In south Dorset a southerly downthrow is shown to be characteristic of the intra-Cretaceous faults and northerly downthrow of the Tertiary faults. The same relationships have been shown to exist in the Boulonnais.

9. The inliers of Oxford Clay and Lower Oolites at Ridgeway and Bincombe can best be explained by supposing that the Abbotsbury and Ridgeway Faults remain parallel for about 5 miles, and that they scissor very obliquely across one another near Upwey, so as to leave, east of that point, a wedge or ridge of older rocks which have remained on the upthrow side of both faults.

10. The famous " dyke " of Oxford Clay at Ridgeway is a slice severed from the downthrow face of the Tertiary fault at the point where the intra-Cretaceous and Tertiary faults nearly coincide.

11. The throws of the faults at Ridgeway and Bincombe have been overestimated.

REFERENCES.

Arkell, W. J., 1933–5. " Analysis of the Mesozoic and Cainozoic Folding in England," XVIth International Geol. Congress, Washington, July, 1933 (abstract). Full text winter, 1935–36.

Bristow, H. W., 1852–5. Horizontal Section No. 20 (1852) and Sheet 17, Geol. Survey Map, Old Ser., 1 inch to 1 mile (1855).

Buckland, W., and de la Beche, H. T., 1836. " On the Geology of the Neighbourhood of Weymouth and the adjacent parts of the Coast of Dorset," *Trans. Geol. Soc.*, iv (**2**), 1.

Conybeare, W. D., 1822. " Isle of Purbeck," in Conybeare and Phillips, *Outlines of the Geology of England and Wales*, Sect. iii (e), 110.

Dines, H. G., and Edmunds, F. H., 1927. " The Tectonic Structure of the Hogs Back," *Proc. Geol. Assoc.*, xxxviii, 395.

Fisher, O., 1896. " Vertical Tertiaries at Bincombe, Dorset," Geol. Mag., p. 246.

Hudleston, W. H., 1889. " Excursion to Weymouth," *Proc. Geol. Assoc.*, xi, p. xlix.

Pruvost, P., 1922. " La faille de Landrethun et son prolongement au Cap Gris-Nez," *Ann. Soc. géol. du Nord*, xlvi, 54.

Rowe, A. W., 1901. "The Zones of the White Chalk of the English Coast—Part 2, Dorset," *Proc. Geol. Assoc.*, xvii, 1.

Strahan, A., 1895. "On Overthrusts of Tertiary Date in Dorset," *Quart. Journ. Geol. Soc.*, li, 549.

—— 1898. "The Geology of the Isle of Purbeck and Weymouth," *Mem. Geol. Surv.*

—— 1904–5. Sheets 341–3, Geol. Survey Maps, colour printed, 1 inch to 1 mile.

—— 1906–1932. "Guide to the Geological Model of the Isle of Purbeck," 2nd ed., 1932, *Mem. Geol. Surv.*

Stuart, M. G., 1889. "The Ridgway Fault," *Proc. Dorset Field Club*, x, 55.

Turner, J. S., 1935. "Structural Geology of Stainmore, Westmorland," *Proc. Geol. Assoc.*, xlvi, 121.

Webster, T., 1816. Letters from Dorset, in Englefield, H., *Picturesque Beauties of the Isle of Wight* (written 1812, with drawings).

Weston, C. H., 1848–9. "On the Geology of the Ridgway near Weymouth," *Quart. Journ. Geol. Soc.*, iv, 245, and v, 317. Also in viii, 110 (1852).

White, H. J. O., 1921. "A Short Account of the Geology of the Isle of Wight," *Mem. Geol. Surv.* (revision and abridgement of a larger memoir by Bristow, revised by Strahan, and published in 1889).

Woodward, H. B., 1895. "Jurassic Rocks of Britain," vol. v, *Mem. Geol. Surv.*

POSTSCRIPT NOTE.

On 1st August, 1935, when this paper had been completed, *Abstracts of the Proceedings* of the Geological Society of London, No. 1299, dated 23rd July, was received. It contains an abstract of a paper by Dr. J. V. Harrison on "Gravity Collapse Structures and Mountain Ranges, as exemplified in South-western Persia", and in a contribution to the discussion Dr. G. M. Lees "exhibited as an example a lantern-slide showing the crumpled Purbeck Beds of Lulworth Cove, and said that, in his opinion, this crumpling was due to slipping rather than to tectonic pressure. Even the Purbeck thrust-fault became suspect when analysed in detail. The hade of the so-called thrust did not conform to that of a normal thrust, and he suggested that in this case also slip phenomena might provide the true explanation".

I immediately sent a copy of my paper to Dr. Lees, and he kindly criticized it. Some of his criticisms have led to alterations in the text, usually in the directions of greater caution and greater clarity in statement. I wish to acknowledge my gratitude to Dr. Lees for this kindness, and also to Professor V. H. Mottram and Mr. Brian Mottram for taking for me some photographs on which Text-figure 6 is based, when I was without a camera in Dorset.

Notes on the Pre-Cambrian of the Canadian Shield with Reference to Pre-Cambrian Nomenclature.

By the late R. W. Brock.

On 31st July, 1935, Dr. R. W. Brock and his wife were killed in an aeroplane accident at Alta Lake, British Columbia, while on the way to the Bridge River mining area, and some notes regarding the conditions under which this paper appears are necessary.

During seven years close association with Brock I had frequent opportunities of discussing with him the various views held regarding the classification of the rocks of the Canadian Shield and learned from him many of the details of the history of its growth. When, therefore, the British Association arranged for a discussion on the pre-Cambrian, to be led by Sederholm, at its Aberdeen meeting in 1934, I asked Brock if he would care to let me have an outline of his views which might be helpful on that occasion, the more so as just three or four years before he had spent a considerable time in Finland with Sederholm. He agreed to this, and sent me such an outline in a form, however, intended only for verbal presentation to the meeting in the way that should seem to me most suitable at the time. When, owing to the death of Sederholm, this part of the Aberdeen programme was cancelled, I wrote to Brock asking if he would publish the notes he had sent me. These, however, he did not consider suitable for more public presentation, but he said that he would revise them with that end in view.

A few days before his death, when I saw him in Vancouver last summer, he told me that he had been going over the notes again and that he had extended their scope a little to draw some comparisons with the pre-Cambrian of Fennoscandia. A month later his secretary informed me that she had completed the typing of the paper here given and asked if I would take the matter in hand. After comparing the new draft with the original notes, I felt certain that it had been intended as the final form for publication and I have left it untouched except for minor typographical errors and details.

Though throughout his life Brock was in the closest touch with the problems of the pre-Cambrian geology of Canada, since his first entry as a young assistant into the Geological Survey and later as its Director, this is, I believe, the only comprehensive statement he has given of his views on these matters.

T. C. Phemister.

THE pre-Cambrian geology in Canada is in an unsatisfactory condition, due not so much to disagreement regarding fundamental facts and history, as to words and the control they exercise upon ideas.

There is a general agreement among the abler geologists regarding main facts but there are no sharply defined, accepted terms to represent these facts. Nomenclature is in a chaotic state.

Canada possesses about 2,000,000 square miles of rocks classed as pre-Cambrian, perhaps the largest single area of such rocks anywhere exposed. It was in this area that the first light was shed upon the early history of the earth, and it still furnishes perhaps the best field for the elucidation of the problems that beset the study of this early history. To understand the causes of the present unsatisfactory condition of the study, and to separate the wheat from the chaff, it is helpful to treat the subject somewhat historically.

Sir William Logan by his Canadian work did for the pre-Cambrian what William Smith did for the Carboniferous and Mesozoic, what Cuvier and Lyell did for the Tertiary and what Murchison and Sedgwick did for the pre-Carboniferous Palaeozoics. Logan's work was only a few years later than Murchison's and Sedgwick's. He belonged to their period.

The reliance to be placed upon a man's work depends naturally upon his character and natural capacity and these are shown by the recognition accorded his work by his fellows, but still better by the recognition he receives, and the estimation in which he is held, by outsiders. Unless a man strikes an outsider as a great man, he is unlikely to be genuinely strong even in his own particular line.

Nine years after Logan began his official work in Canada he exhibited his geological map of Canada with illustrative specimens at the London Exhibition. For these he received a letter of thanks from the Prince Consort and was elected a Fellow of the Royal Society. A few years later, at the Paris Exhibition, he was awarded the Grand Gold Medal of Honour and made a Chevalier of the Legion of Honour. In all he received twenty medals for his work in Canada.

In his lifetime he was regarded as the most outstanding non-political Canadian, and to-day he is regarded as one of the half-dozen greatest men Canada has produced. His geological work was what might be expected of such a man—it still stands as does that of the other leaders of the Heroic age of geology.

Logan had one great advantage over a large number of workers who have followed him in the pre-Cambrian field, in that he was a first-class geologist and an outstanding stratigrapher before he began work on the complicated and difficult pre-Cambrian. He knew how to apply stratigraphical methods. He knew what to look for, and he recognized it when he saw it, even if it were somewhat obscure or disguised. For instance, after his work on the coal deposits of Swansea, Dr. Buckland referred to him as " the most skilful geological surveyor for a coal mine I ever have known ".

Logan began his work on the pre-Cambrian north of the St. Lawrence and on the lower Ottawa. Here he found a group of rocks extending from the Atlantic to Georgian Bay of Lake Huron, characterized throughout by their highly crystalline state, intense folding and contortion, faulting, and such evidences of extreme disturbance. The dominant gneisses were often interbanded with crystalline limestones and quartzites, so might be presumed to be sedimentary also. These rocks were not " primitive " but must belong to Lyell's new class of rocks, the " metamorphic ". For some years he called this group " the Metamorphic Series ". The relationship of the *granitic* gneisses, that occur over vast areas, to the sedimentary limestones was not clearly seen, though they were often interbanded. Since, however, the lowest rocks were always these granites or gneisses, he thought it best to assume that stratigraphically also they underlay the limestones. (With the advent of modern petrographical methods, Adams proved that some of the gneisses are sedimentary, though the majority of them are igneous and have an intrusive contact with the sediments.)

Logan came to refer to the sediments as the Grenville series, and to the granite-gneisses as the Ottawa Gneiss. He found the "Metamorphic Series" cut by younger, unmistakably igneous rocks, "granites, syenites, feldspar porphyries, dolerites, anorthosites." Since their precise age could not be determined further than that they were younger than the metamorphic series and older than the fossiliferous, he did not treat them separately, but described them with his metamorphic series. But it is to be noted that he always recognized, and referred to, them as younger than the latter.

In his 1845 report, Logan describes a series of unmistakable sediments he found on Lake Temiskaming. Even where highly disturbed, as they generally were, and altered sufficiently for the resulting cleavage to cut through boulders and matrix of a conglomerate as if it were a homogeneous rock, and for the conglomerate to erode and weather as if it were homogeneous, the sedimentary nature of the rocks was always strikingly evident. In this respect they differed absolutely from the rocks of the Metamorphic Series. Thus he had two distinct groups of rocks in his "Azoic". The relationship between the two was never in doubt. The Temiskaming sediments held boulders of the older metamorphic series from which they were separated by a great unconformity, for the interruption in sedimentation was sufficient for the older group to be greatly disturbed, *highly metamorphosed*, and eroded *before* the younger beds were laid down.

The following year he found two precisely similar groups of rocks, metamorphic and sedimentary, similarly separated by a major unconformity, at several points on the east shore of Lake Superior, and also in the Thunder Bay district at its west end.

But here above his younger (Temiskaming) group, which at first he called the Lower Copper-Bearing Series, and separated from it by a major unconformity, he found a series of flat-lying rocks which he called the Upper Copper-Bearing Series, consisting of two groups, a lower one, immediately overlying the great unconformity, consisting of bluish slates or shales interstratified with sandstones and beds of trap, which he referred to as the "Lower Group" and "reposing" upon this system (disconformably), an upper system consisting of a succession of sandstones, conglomerates, indurated marls and limestones, often red in colour, also interstratified with trap which is often amygdaloidal. This system he referred to as the "Upper Group" of the "Upper Copper-Bearing Series". (Later these systems have come to be known as the Animikian and the Keweenawan.) This Upper Copper-Bearing Group, although unfossiliferous, he (and some other good geologists of later years) considered to be Palaeozoic.

This point must be borne in mind ; on Lake Temiskaming he had found only the lower limit of his second sedimentary series, but not the upper (as a matter of fact, he wrongly included in it a group of quartzites that Miller later found to overlie his second great unconformity) ; on Lake Superior, however, he had found the top of the group as well as the bottom. It was bounded above and below by great unconformities. This series then embraced all the rocks lying between these two great unconformities, *but nothing else.*

In 1847 and in several other field seasons, Logan's assistant Murray worked on the rocks along the north shore of Lake Huron and neighbouring districts. Murray found the " Metamorphic Series " unconformably overlain by sediments which he took to be Logan's Temiskaming rocks, as indeed many of them are. Unfortunately he considered all the North Shore rocks, sediments, greenstones and intrusives to belong to one group, whereas many of them really belong to Logan's Upper Copper-Bearing Series, above the second great unconformity.

In the summer of 1848 Logan himself spent two and a half months on the North Shore, but his time was spent mainly on a study of the mineral deposits, while the areal geology was left with Murray. Logan does not appear to have done any further work on the North Shore of Lake Huron. Having on Lake Superior determined his three groups of rocks by great unconformities, he left the North Shore of Lake Huron to be worked out by Murray, and Logan merely incorporated Murray's results in his map, and in the 1863 report summarized the geology of Canada as worked out by the Geological Survey up to that date.

In his 1852 report Logan substitutes the term " Laurentian " for his former " Metamorphic Series " ; " since the term metamorphic series is applicable to any series of rocks in an altered condition, and might occasion confusion, it has been considered expedient to apply to them for the future the more distinctive appellation of the Laurentian Series, a name founded on that given by Mr. Garneau to the chain of hills which they compose."

In the report for 1856 the term Huronian is used for his " Second Series ", and in a paper read before the American Association for the Advancement of Science in 1857 he did what was somewhat unusual in those days, he defined precisely his new terms. The term Huronian was applied to the pre-Palaeozoic rocks above the unconformity at the top of his Metamorphic Series. (It is to be remembered that pre-Palaeozoic as used by Logan means below the unconformity at the base of the Lower group of the Upper Copper-Bearing Series (Animikian).) As noted above, in his 1846 report he explicitly gives this unconformity as the upper limit of the rocks he now proposed to call Huronian. He always considered his Upper Copper-Bearing rocks—both groups—Palaeozoic.

In the Huronian as thus defined Logan recognized not only sedimentaries, but greenstone bands, which might be flows or sills, and dykes which he considered their probable feeders. He also recognized and included in the group intrusive granites which "thrust aside and cut the series including the greenstone dykes". These granites antedated the Post-Huronian unconformity but represented the last event in Huronian times.

In his Huronian Series he found a record of Post-Huronian events in intrusions of a Post-Huronian greenstone and mineralization.

His inclusion of the granite and other intrusives in his group, and his remarks about Huronian and Post-Huronian events, and his selection of unconformities as boundaries, show that he was using the term to denote a period of time quite as much as to designate the assemblage of rocks formed during such a period.

Having given a name to the group of rocks between the great unconformities, he proceeds, "A distinctive name having been given to this portion of the Azoic rocks renders it necessary to apply one to the remaining portion." This defined the Laurentian, all rocks antecedent to the unconformity at the base of the Huronian. This would, of course, include any igneous rocks formed during this period of time, just as he specifically stated his term Huronian did.

As it turned out, it is a pity he applied the term Huronian to the second era. Had he called it Temiskamian after the locality where he first encountered his Huronian rocks or better still Superian, where he had both limiting unconformities that defined his Series, it would have focussed attention upon the real "original Huronian", whereas the term Huronian focussed attention upon the north shore of Lake Huron, where his assistant wrongly grouped Animikian rocks with true Huronian. But having used the term Huronian for the second series of rocks, it might have been better to have used the term Superian for his third series that lay above the second unconformity instead of the descriptive expression Upper Copper-Bearing Series, for the latter rather suggests a somewhat close connection with the "Lower Copper-Bearing Series" as the Huronian was often called. What future geologists required was emphasis on the unconformity that separated the two and formed the basis of his classification. Logan, however, required public support to keep his survey in existence, for which reason the economic side of the work had to be stressed. This made the descriptive term valuable. Moreover, there was the hope that the Palaeozoic age of the Upper Copper-Bearing rocks would be established, and Palaeozoic names already established would then be applicable to them. "The affinities of the red sandstone of Sault Ste. Marie would thus appear to bring it into the position of Chazy rather than Potsdam and if this were established the copper-bearing portion of the Lake Superior rocks might reasonably be considered to belong to the Calciferous and Potsdam."

Logan's inclination to regard the Animikian and Keweenawan as Palaeozoic has been shared by a highly respectable group of geologists down to the present, and the number is increasing now that undoubted Middle-Cambrian fossils have been found in what has always been considered typical Keweenawan.

But since these rocks are unfossiliferous, and so have to be studied by the same methods as the undoubted pre-Cambrian, and since geographically they are in close association with the latter, it has been more convenient to consider them all together as a unit. The question of their precise age, with no means of settling it, has not been a live issue.

Logan's classification, then, was as follows :—

Palaeozoic ?	Upper Copper-bearing Series	Upper Group Disconformity Lower Group
	Great Unconformity	
Azoic	Huronian (Lower Copper-bearing Series)	Intrusive granite Intrusive greenstone Sediments with interbanded greenstones
	Great Unconformity	
	(In the Laurentian are post-Laurentian intrusives of unknown age)	
	Laurentian	Grenville Sedimentaries Granitic gneisses. Ottawa Gneiss

Nothing could be clearer than Logan's classification or the foundation on which it is based. It provided for all the rocks then known and also for any to be discovered. If older than the first great unconformity, the rocks were Laurentian ; if they came between the great unconformities they were Huronian ; if younger than the second unconformity they were Upper Copper-Bearing. So it is not surprising that in the ninety years that have elapsed since Logan discovered the relationships on which it is based, nothing has come to light to necessitate or warrant altering the foundations of that classification or of changing the meaning or use of his terms Laurentian and Huronian.

But while Logan had the perspicacity and the " nose " for critical outcrops that enabled him to secure the main facts in an absolutely determinative way, and to make a proper classification of the rocks, neither he, nor much less anyone else, could map so vast a territory, mantled with primeval forest and without trails, composed of rocks of many different ages but lithologically alike, in various stages of metamorphism and with complex structures, with exposures often scattered and critical areas concealed, and without fossils to assist in age determinations : nor under such conditions could he or anyone else correlate correctly all exposures seen. Mistakes in correlating in the field were bound to occur. Some formations were overlooked, being absent where Logan's careful field work was done. But all this is detail. The main facts of the pre-fossiliferous rocks had been recognized and a sound classification made.

With such a start, the result of the labour of practically one man, it might reasonably have been hoped that in seventy years a striking advance would have been made. There has been progress certainly, but it has been disappointingly slow.

While many factors have contributed to this, the chief reason perhaps was the *Geology of Canada*, the report of the Geological Survey of Canada for 1863, in which Logan summarizes the results achieved by the Survey up to this date.

It became a classic and that was the trouble—its excellence was satisfying and geologists did not bother to go back of it to the earlier reports and papers of Logan. While good, it has several defects. One of the most serious is that it does not define Laurentian and Huronian, but rather takes them for granted. It does not emphasize the unconformity at the top of the Laurentian in the way that is necessary to impress it upon a reader as the basis of the classification. The chapter on the Huronian starts off, "On Lake Temiskaming the Laurentian gneiss *is followed by*," etc. The next chapter on the Upper Copper-Bearing rocks makes a much better start: "The Huronian formation on Lake Superior is *unconformably* overlaid by a second series of copper-bearing rocks which may be divided conveniently into two groups." But it does not state that this unconformity marks the top of the Huronian and that it is everywhere overlain by the succeeding rocks unconformably. To make matters worse, in his table of formations under Azoic he mentions Laurentian and Huronian, but under Palaeozoic he makes no mention of the Upper Coppper-Bearing group, which might lead to a hasty inference that it was included with the Huronian.

In the descriptions under Laurentian and Huronian there are naturally included rocks that do not belong there, due to faulty correlation, and without the strict definition of the series there is no way of telling that Logan did not intend the term to include them. But there are also rocks included in the description because it happened to be the most convenient place to mention them, making the chapter to this extent geographical rather than geological.

A very serious lapse is the statement that Huronian rocks occur at the mouth of the Kaministique river, near Port Arthur, whereas the rocks here are Animikian, the Huronian being exposed only some miles up the river. This contact between the Huronian and Animikian is correctly shown on the geological map with the Animikian forming the whole shore line. But the Lake Superior geologists following the text, thought they were examining Logan's original Huronian. They traced these Animikian rocks, which they supposed to be Logan's Huronian, into their territory south of Lake Superior. Loyal to the laws of nomenclature, they called them Huronian and loyally continued to do so even after they had discovered a major unconformity in the middle of their Huronian. But this resulted in an Upper Huronian, the equivalent of the Animikian and a Lower Huronian corresponding to Logan's Huronian. The name "Huronian" led to the Lake Huron north shore being mistaken for the "original Huronian", and geologists went there to familiarize themselves with it. But this, as we have seen, was not the "original Huronian", it was not even Logan's, and it consisted of both Huronian rocks and younger ones that by Logan's definition were Animikian. To make matters worse the "original Huronian" of Lake Huron, including both Animikian and Huronian, corresponded exactly with the Huronian south of Lake Superior, confirming the Lake Superior geologists in their unfortunate mistake concerning the Animikian rocks of Port Arthur and in their use of the terms Lower and Upper Huronian. Further, the excellent and detailed stratigraphical work done by the Lake Superior geologists south of Lake Superior on these rocks that were equivalent to the rocks on the north shore of Lake Huron led to the importation of the terms Lower and Upper Huronian into Logan's own country, Upper Huronian being used for Logan's lower group of the Upper Copper-Bearing Series everywhere except around Thunder Bay.

Had Logan's definitions been known and the importance of his unconformities and the use he made of them been recognized, and his stratigraphical methods been followed, no permanent trouble would have arisen. Mistakes of omission and commission, whether on Logan's part or on that of his successors, would have been rectified. This, of course, was what Logan expected; for he knew the limitations of rapid reconnaissance work. This is shown by the way in which, when speaking of the rocks of any one of his groups, he keeps ever repeating "so far as yet known" (or "so far as yet seen") "they consist of", etc. But that was not the way it worked out. Not recognizing the basis of his classification, or the significance of his terms, some later workers considered that error of omission or commission on Logan's part or any addition to knowledge on theirs, invalidated Logan's term, and so either introduced a new term in its place or used the old term in a different way, whichever was worse, thereby experiencing the thrill of improving upon or correcting the master.

Logan recognized granites of different ages and expressly included one great group of them in his Huronian; he recognized greenstones of Huronian and of both Upper Copper-Bearing ages, and mentioned another group of them that might be either Laurentian or Huronian; he found sedimentaries in all the groups from Laurentian up.

Overlooking the geological history on which Logan's classification rested, and which furnishes the only practical basis upon which these rocks can be recognized and assigned to their proper position, some later workers fell back on lithological resemblances for correlations with the disastrous consequences that might be expected. Some put any granite, regardless of its age or relationships, into the Laurentian. Many placed any greenstone in the Huronian. Sedimentaries are so important in the Laurentian that Logan was inclined to believe that the entire Laurentian was highly metamorphosed sedimentaries, yet when the Laurentian granite-gneisses were proved to be intrusive the term was restricted to the igneous rocks. The climax in this direction is surely reached when the series below the post-Laurentian unconformity is defined as igneous and Laurentian sedimentaries must be classified, *ipso facto*, Huronian or later.

With the advent of modern petrographical methods the pre-Cambrian with its wide range of rock types and minerals became an enticing field for petrographical work, and for many years stratigraphical work was overshadowed. This did not apply, however, to the first application of the new petrographical methods in the study of the pre-Cambrian, made in the eighties by Dr. Andrew C. Lawson, at that time a member of the Geological Survey of Canada. Lawson combined petrographical work in the happiest way with keenly applied stratigraphical field work. In the district west of Lake Superior he found that a system of greenstones and schists, hitherto supposed to be Huronian, were volcanics, both basic and acidic, that were intruded and altered by the Laurentian granite, and therefore belonged to Laurentian times. He named this new series the Keewatin. He also noted a granite which cut both these Laurentian rocks and Huronian sediments, and this granite he named Algoman.

The greenstones noted by Logan and Murray "that seemed to come between the Laurentian and Huronian to herald the approach of the latter" were no doubt Keewatin. But Logan did not succeed in getting the exact relationships and therefore could not determine the exact age of these greenstones.

Lawson, while recognizing that Laurentian granite-gneiss cut supercrustal rocks, suggested that this did not necessarily mean that the granites were not the floor upon which the volcanics and sediments were laid down. It might be simply a case of refusion of the floor.[1]

This hypothesis merits serious consideration. No other base for the supercrustal rocks has been found anywhere. These old granite gneisses differ from later granitic intrusions in several important respects :—

First : In the enormous areal extent of these old rocks. There is nothing approaching this in any later intrusions, and it is difficult to imagine any mechanism that could produce such results by batholithic intrusion.

Second : While the old granites sometimes exhibit "lit par lit" injection forming migmatites, intimate interweaving of the magma in the schists is comparatively rare. Mixed rocks in the Laurentian are common, but it is a later granite that is responsible for the majority of them.

---

[1] *Annual Report Geol. Survey of Canada*, 1887–8, vol. iii, pt. i, p. 139 F.

Third: More striking still is the marked absence of mineralization by the old granites. It is often suggested that this is due to heavy erosion having removed all traces of mineralization, but there are numerous areas of roof rocks preserved, just the place where mineralization, had there been any, would have taken place. The conclusion seems inevitable that this magma, unlike ordinary granitic magmas, contained little if any mineralizers, suggesting a refused rock rather than a primary magma.

Refusion would explain all the differences noted as well as solving the problem of the basement upon which the supercrustal rocks were laid down.

Dr. Frank D. Adams followed with the proof of the intrusive contact between the Laurentian granite-gneiss and the Grenville sediments. The importance of these contributions is obvious. Numerous other workers added steadily to the general knowledge of the pre-Cambrian rocks, particularly with their distribution in the Canadian Shield. Some excellent mapping was done, notably Adams and Barlow's map, of the Haliburton-Bancroft areas and Coleman's map of the Sudbury basin. The latter would be a first-class performance to-day, when the district is cleared and opened up. Considering the physical difficulties at the time the mapping was done, it is not extravagant to call it remarkable.

During the closing decades of the last century the progress along taxonomic lines left more to be desired.

In the first decade of the new century, through the fog which had again descended upon the taxonomy of the pre-Cambrian of Canada, and in which it was so easy to lose one's way, came a further ray of sunlight to illumine the scene. This was the work of Dr. W. G. Miller in the Cobalt area, in the region where Logan first discovered the dual nature of his "Azoic". Like Sir William Logan and Dr. George Dawson, Miller had an uncanny instinct for locating crucial points where the necessary evidence for solution of the problem was to be found. Even in the highly metamorphosed Grenville or Keewatin he could find the spot where the story was decipherable and clear. Through the sheer quality of his work, for he was the most modest and retiring of men, his exceptional worth was quickly recognized by the mining world, which induced the Government to bring him to Toronto from a professorship at Queen's University, Kingston, and to create for him the position of Provincial Geologist, in which his whole time would be spent on creative work. In recognition of the value of his field studies while in academic work, the Government presented the University with a building for its geological department, and, though it was against their policy at that time to subsidize any other University than the Provincial one at Toronto, they gave a substantial annual grant to the Science

Faculty at Queen's. After his death in 1925 a monument to his memory was unveiled at Cobalt, which bears this inscription :—

> TO COBALT HE GAVE ITS NAME
> AND A PLACE AMONG THE GREAT MINING
> CAMPS OF THE WORLD.
> HE READ THE SECRETS OF THE ROCKS
> AND OPENED THE PORTALS FOR THE OUTPOURING
> OF THEIR WONDERFUL RICHES.
> HIS MONUMENT IS
> NEW ONTARIO.

In public appreciation he ranked with Logan and Dr. G. M. Dawson, an appreciation due, in his case as in theirs, to a recognition of the outstanding quality and reliability of his work and of the greatness and character of the man, qualities that show in the work as well as in the man. The work of such an one must be given precedence over that of the majority of investigators.

After his discovery of silver in the Cobalt district, Miller worked out the geology of the district in detail. In this work he had the help of his assistant geologist, Mr. Cyril W. Knight. He worked it out from first principles uninfluenced by any work or conceptions formed by Logan.

The oldest rocks were altered volcanics passing upward into iron-formation, jaspilite, slates, and graywackes. Physically and in age relationships the volcanic rocks correspond to the Keewatin of Lawson. The Laurentian granite-gneiss is absent in the district proper but occurs nearby where it cuts the Keewatin. These rocks are followed by a major unconformity.

Overlying these lower rocks unconformably is a series of sediments with basal conglomerate containing the débris of the *already metamorphosed* older rocks. To this system he gave the name Temiskaming Series. Interbanded with the sediments and cutting them were sills and dykes of basic rocks. These were not very important in the Cobalt area, but proved to be so in many other parts. All these rocks are disturbed and cut by a granite which he called Lorraine. The disturbance was of a major order. The Temiskaming series is everywhere on edge and is squeezed and somewhat metamorphosed.

During the period represented by the succeeding great unconformity the mountains thus formed were peneplaned, and on this surface the next succeeding system of rocks was laid down. To these Miller gave the name Cobalt series. The lowest member is a conglomerate which contains numerous boulders of the Temiskaming rocks and of the Lorraine granite. The Cobalt series is mostly flat-lying, little disturbed and unmetamorphosed, resembling in position and physical characters the Animikian rocks.

The Cobalt series is cut by a diabase which is responsible for the mineralization. In relative position, composition, and mineralizing influence it is like a Keweenawan intrusive.

His geological work on this district was put immediately to the severest test by the corps of geologists engaged by the mining industry, not only by surface observation, but by detailed study of miles of underground workings. But it has stood up to all tests. Thus the accuracy and reliability of his field work has been thoroughly established.

Working independently from first principles, applying strictly stratigraphical methods, Miller arrived at precisely the same geological history and classification as Logan. For the sake of comparison Logan's classification of the pre-fossiliferous rocks and Miller's classification of the rocks of the Cobalt district are given below placed side by side.

<table>
<tr><th>MILLER</th><th>LOGAN</th></tr>
<tr><td>Cobalt District
Nipissing Diabase</td><td>Upper Copper-Bearing Series
(Keweenawan) Upper Group</td></tr>
<tr><td colspan="2">Disconformity</td></tr>
<tr><td>Cobalt Series</td><td>Upper Copper-Bearing Series
Lower Group</td></tr>
<tr><td colspan="2">Great Unconformity</td></tr>
<tr><td>Lorraine Granite
Igneous contact
Lamprophyre Dykes
Igneous Contact
Temiskaming Series (Sedimentary)</td><td>Huronian { Huronian Granite
Igneous contact
Huronian greenstone
Igneous contact
Huronian sedimentary</td></tr>
<tr><td colspan="2">Great Unconformity</td></tr>
<tr><td>Granite Gneiss (Laurentian)
(In neighbourhood but not exposed in Cobalt District itself)
Igneous contact
Sediments—Iron Formation</td><td>Grenville</td></tr>
<tr><td>Keewatin Complex</td><td>Ottawa Gneiss
(should have been above Grenville)
(not recognized by Logan.)</td></tr>
</table>

The history is the same in both. Logan named the eras below the great unconformities. He named the two systems he had found in the Laurentian and the members he had found in the Huronian. Miller makes the same divisions and subdivisions, but while he emphasized the eras he does not name them, for the avowed reasons that Logan's old names had been misapplied and ruined, and no later terms were usable, and new names would add to the chaos in nomenclature.

In 1914 the Ontario Bureau of Mines published a report (vol. xxii, part ii) by Miller and Knight on *The Pre-Cambrian Geology of South-Eastern Ontario.* As this district has not experienced any great mining development since that date, this report has not received the attention it deserves, nor its conclusions the verification that those of the Cobalt report received. But it is safe to infer that it is equally accurate and reliable. As a matter of fact, Miller, here as elsewhere, took many leading geologists to his critical localities and they were satisfied with his evidence and deductions.

This work is exceedingly important, particularly at the present moment when the nature and age of the Grenville is being questioned, not by those who have studied it, but by those whose experience with rocks of the oldest era has been in districts where the sediments are lacking.

It confirms the conclusions of Logan that the great Grenville sedimentary series is a Laurentian system metamorphosed *before* the first great unconformity, for the conglomerates of the system succeeding this unconformity, the Hastings Series, are full of pebbles and boulders of Laurentian gneisses and Grenville crystalline limestones.

This metamorphism is not post-conglomerate, for the Hastings series, while deformed, tilted, and somewhat metamorphosed, is not strongly metamorphosed as are the pebbles, though the Hastings limestones would metamorphose more readily and quickly than the pebbles of the conglomerate. It is true that locally the Hastings rocks may be completely metamorphosed, but this is contact-metamorphism due to the invading Moira granite. Another discovery most important in pre-Cambrian geology is the probable relationship between the Grenville and the Keewatin.

At a number of points not seen by Logan, Miller and Knight found the Grenville extending downward through schistose quartzites, schists, and iron-formation into a volcanic complex in all respects similar to the Keewatin of Northern Ontario and Quebec and of the Lake Superior district, where the Keewatin extends upwards into the iron-formation and in places into quartzites and schists but where the limestones of the Grenville, almost without exception, have not been found.

Consequently in the districts previously examined, no evidence had been found regarding the relationship of the Keewatin to the Grenville, though it had been suspected.

This work established the fact that the volcanic complex is our oldest known formation and that it passes upward into a sedimentary series, presumably the Grenville, as it proved to do in Eastern Ontario. (Lawson's Couchiching series of metamorphosed sediments that he thought to be older than the Keewatin have been shown by recent work to be in all probability younger, i.e. Grenville, the apparent inferior position being due to faulting and overthrusting.)

A third point of interest in connection with this work is that it settles the position of the Hastings series. This succeeds the great

Post-Laurentian unconformity ; it is cut by basic intrusives and it and these by a later granite. In position, attitude, degree of metamorphism, rock-content, and history, it corresponds exactly with Miller's Temiskaming or the Huronian as defined by Logan.

A valuable feature of this report is his table showing his conception of the correlation of the pre-Cambrian rocks of south-eastern Manitoba, Ontario, and Western Quebec, facing page 126, and an appendix of notes on the different districts. His work as Provincial Geologist had taken him to most of the districts mentioned, so the correlation is based upon much personal knowledge as well as description by others.

It is interesting to note that over such a vast stretch of territory, wherever the rock relationships have been determined with some accuracy, they fall into appropriate positions in the classifications of Miller and Logan. But the same holds true throughout the entire Canadian Shield.

Though it might not be suspected, the truth is that most pre-Cambrian geologists of America are agreed upon the main facts in its geological history utilized in the above classification ; the discussion and strong differences of opinion arise when a name is introduced. This was well illustrated a few years ago when representative pre-Cambrian geologists, attending a meeting of the Geological Society of America, got together to discuss pre-Cambrian classification and nomenclature. I insisted upon discussing the history without the use of names. Unanimous agreement was speedily reached upon these points :—

A.—1. A major unconformity after the intrusion of the first granite-gneiss.

2. This intrusion was on an enormous scale, marking a revolution of the first magnitude.

3. Calling this Era A, and the unconformity, the Post-A unconformity, and the rocks formed during Era A, Group A—Group A is characterized by extreme disturbance, intense folding, and high metamorphism.

Though the point was not raised, it was evident that Logan's term " the Metamorphic Series " was justified so far as the physical character of the rocks of the group is concerned.

B.—1. A major unconformity follows the intrusion of the second granite.

2. This intrusion was on an enormous scale marking a revolution of great magnitude.

3. Calling the era between these two unconformities B, the unconformity the Post-B unconformity, and the rocks formed between Post-A and Post-B unconformities, Group B—the Group B rocks are characterized by high disturbance ; they are generally vertical or nearly so ; they show decided effects of dynamic metamorphism, but excepting locally, there is no difficulty in recognizing immediately that they are sedimentary, volcanic, or

intrusive, as the case may be. In this respect they differ markedly from the general character of rocks of Group A. One geologist suggested that some granites, generally supposed to be Group B granites, were really later and that these later granites were responsible for a good deal of the disturbance which in this case would not be confined to rocks of Group B or Group A, but even he agreed to the three points noted, B 1, 2, and 3.

C.—Formations younger than the Post-B unconformity, i.e. belonging to Era C, are *generally* little disturbed, and generally flat-lying or dipping at low angles. They resemble Palaeozoic formations that are poor, or entirely lacking in fossils.

D.—The rocks of Era C fall into two systems separated by a disconformity. Locally there may be an intraformational break in the sediments of the Lower System of C and also in the sediments of Group B.

At this point someone insisted on introducing a name and the gathering broke up.

From this it is evident that the geological history of the pre-Cambrian, recognized by Miller and by Logan before him, is accurate and satisfactory so far as it goes. That being admitted, their classification, which is based on it, is scientific and correct. Logan properly named the Eras and therefore the rock groups, previously unrecognized and unnamed. Miller, on account of there being too many names already, mostly improperly applied, refrained from adding to the confusion, but contented himself with leaving the great divisions nameless and using local or only defined and widely recognized names for systems and series.

But names are absolutely essential, names that are sharply defined, to refer to natural subdivisions, otherwise the natural facts will be overlooked, woolly thinking, confusion, and chaos, will be perpetual. By all the rules of nomenclature, Logan's terms Laurentian and Huronian used as he defined them, and intended them to be used, should be readopted. The term Superian might be added for Era C and the rock systems following the Post-B unconformity.

Returning the term Laurentian to its old place should not present much difficulty. Huronian is more difficult. It has been used in such different senses and to include so much. But the difficulties are not insuperable if agreement can be secured to limit the name as Logan did to the rocks between the two major unconformities. Confusion may be avoided by using Miller's term Temiskamian for the sedimentary rocks of the Huronian. It has not been misused, as yet, and it is a reminder of Logan's first encounter with his Huronian, where he found its base and discovered that his Azoic consisted of two Eras. It would help to transfer the idea of "original Huronian" to where it belongs.

Animikian and Keweenawan may very well stand for the Lower and Upper groups of Logan's Upper Copper-Bearing Series or Superian (let us call them), thereby following Logan's practice and in remembrance of the fact that he first encountered, recognized, and defined these groups on Lake Superior, where perhaps, they are best exposed.

The fact that these names are not " ozoic " is rather an advantage, for the rocks are unfossiliferous and so tell nothing of the dawn of life or of primitive life. The terms raise no false hopes, make no promises they are not prepared to fulfil. Since these eras are much the longest and most eventful in geological history, and are separated by major, probably the greatest unconformities in geological history, no two of them should be united under a common name. Should the Keweenawan eventually prove to be Cambrian the term Superian would drop out. Should the Animikian also prove to be Palaeozoic, it would be placed where it belongs and the Post-Huronian unconformity became the unconformity at the base of the Palaeozoic, as Logan was inclined to suspect it was.

Fortunately it is only concerning names for the eras and groups that there need be any difficulty. Keewatin, Grenville, and Laurentian granite or gneiss are now in general use with the happiest results. The Huronian, Animikian, and Keweenawian sediments may be subdivided into Lower, Middle, or Upper, etc., series, where it is found that the system can be subdivided. The names Huronian volcanics, Huronian intrusives, and Huronian granite, Animikian greenstones, etc., will fill requirements in distinguishing them from earlier or later eruptives.

Recently Collins and Quirke have emphasized the importance of a disturbance at or near the close of the Keweenawan, raising it to the rank of a revolution, and this idea has found favour with the Lake Superior geologists. But it is to be remembered that the small pre-Cambrian area, south of Lake Superior, where such detailed and conscientious work has been done, is peculiar in the extent to which it has suffered local disturbances in Animikian and Keweenawan times. In the Keweenawan these were great enough for a recognizable overthrust and exceptionally heavy vulcanism.

But the Animikian and Keweenawan rocks are found at intervals all over the great Canadian Shield on both sides of Hudson Bay and along the Arctic where they almost universally lie at low angles, though often affected by great faults. The great revolutions, the only ones observable in the pre-Cambrian as a whole, are those at the close of the Laurentian and of the Huronian. Throughout the whole pre-Cambrian are found synclinal troughs of Huronian or Laurentian rocks at high angles, often reversed. During the great period represented by the Post-Huronian unconformity, the mountains formed by the Huronian Revolution, which closed the period, were worn down to base level. The Animikian conglomerates are full of boulders and other products of the Huronian including its granite. The surface on which the Animikian and Keweenawan rocks were laid down is similar to that of the present day, even in areas where no protecting overlying rocks have ever rested, so far as known or suspected. Even the great valleys by which its surface is now trenched extend under the Animikian and Keweenawan rocks. These rocks rest upon the same sort of surface and in the same way as do the fossiliferous Palaeozoic rocks when the latter are in contact with the Huronian or Laurentian. Except for the absence of fossils they are so similar in appearance and attitude to the Palaeozoics, that such geologists as Logan, Selwyn, Dawson, Winchell, Lane, and others, considered them Cambrian. How could they have done so, if a major unconformity separated the Keweenawan from the Upper Cambrian. Mountain-building of the first order and subsequent peneplanation to the general level of the pre-Cambrian must produce such an unconformity. Where is it and where is the débris from such erosion ?

It is true the Keweenawan was a period of heavy vulcanism and the channels up which such volumes of lava poured must have large dimensions and be filled now with coarsely crystalline rocks of plutonic texture. The lavas show strong differentiation, both basic and some acidic being found. The corresponding intrusives may be expected to show like differentiation, as in truth they do. The majority are basic (gabbros, etc.), but granitic types also occur. While in large enough bodies to be described as batholiths, as that term is defined, they are not as a rule unduly large for volcanic plugs. For instance, a present-day volcano, Mount Aso in Japan, has a crater 20 × 16 km.—its volcanic plug will make a quite respectable batholith ! Further, the Keweenawan coarsely crystalline intrusives have the texture of volcanic plugs or intrusives, and similar limited metamorphosing effects. Sudbury furnishes an excellent example of one of the Keweenawan volcanic centres, strikingly similar to Rossland B.C., a Tertiary centre.

Activity on this scale causes considerable local disturbances, such as are met with in the long volcanic belt that stretched along the border of the pre-Cambrian in the Great Lakes region. It appears that the observed phenomena can be explained satisfactorily by Keweenawan vulcanism, and the very widespread and effective Huronian mountain-building, without raising the serious difficulties introduced by the hypothesis of a Keweenawan revolution rather than a Keweenawan disturbance.

Miller spent a considerable time on the north shore of Lake Huron, not enough to work out in detail the geology of so complicated an area, but sufficient to convince himself that there was a considerable amount of his Temiskamian present as well as his Cobalt series (Animikian). (Incidentally it may be remarked that he considered that the Animikian rocks of Lake Huron consisted of two units separated by an intra-formational unconformity.) He is not apt to be mistaken on either of these systems, with which he was so familiar and which he so well knew how to determine. At the eastern end of the north shore area one might easily be mistaken, for here the measures are overturned as the ripple marks prove.

As mentioned above, the suggestion that the Grenville may be altered Huronian or Animikian, cannot be entertained since the conglomerates of the Hastings Series prove that the Grenville was metamorphosed before the Post-Laurentian unconformity. Further proof, if required, is furnished by the facts that throughout the Canadian Shield (1) the Laurentian is everywhere metamorphosed, while the Keweenawan granitic rocks are small, of very local occurrence, and produce almost no metamorphism: (2) where the Laurentian and Huronian occur together, the Huronian is never in the highly metamorphosed condition of the Laurentian; and (3) the characteristic areal feature of the Animikian and Keweenawan is their undisturbed condition.

To the writer, more striking than the differences is the parallelism of rock-content and geological history between the Canadian pre-Cambrian and the pre-Cambrian in other parts of the world, for example Finland, where fifty years of sound stratigraphical work by Sederholm and his assistants has produced a clear, accurate, and, it would appear, tolerably complete history and classification of the pre-Cambrian. Four years ago I had the good fortune of seeing Sederholm's type localities throughout the country, mostly under the guidance of Sederholm himself, and when he was not present under that of his able colleagues.

Sederholm recognizes in the pre-Cambrian of Fennoscandia four cycles of sedimentation and igneous intrusion, separated from each other by great unconformities.

I.

There is the Oldest Complex which he calls Katarchean, consisting of metamorphosed volcanics, with some iron ores partly magnetitic and partly hematitic, the "leptites" of middle Sweden, succeeded by sedimentaries—a few conglomerates, quartzites, and crystalline limestones. The latter are sometimes very thick. These metamorphosed volcanics and sedimentaries he calls Svionian.

Sederholm considers the Svionian sedimentaries similar and formed in the same way as the Bothnian and later sedimentaries. Miller and some other geologists who have studied the much more plentiful sediments of the Grenville series, are inclined to consider them chemical precipitates and volcanic fragmental material. The lowest part of the Grenville is contemporaneous with Keewatin lava flows, which are often submarine flows. The fine-grained ash would readily alter to clay in the sea water. Among the reasons for the above suggestion are the facts that no evidence of land or surface erosion has been found, and one of the chief characteristics of the Grenville sediments is their unusual fineness of grain. They are cut by post-Svionian granite gneisses that form the country-rock of large areas.

The Svionian volcanics and sedimentaries are analogous to the Keewatin and Grenville, the chief difference being that in

Fennoscandia the volcanics are dominantly acidic (though in southern Finland the acidic are less common), whereas in the Keewatin, basic volcanics are more important. In fact, the resemblances between Sederholm's Katarchaean of Fennoscandia and the Laurentian of North America as defined by Logan are almost perfect. Both form a Fundamental Complex so highly metamorphic that it is often difficult to find spots where the original nature of the rock can be discerned.

As in Canada, so in Sweden and Finland, for long the granite-gneisses were considered the basement upon which the supracrustal rocks were laid down, perhaps representing the first consolidated rock of the earth. In both regions later study revealed the fact that these granite-gneisses penetrate the supracrustal rocks, though in Fennoscandia doubt exists about all the old gneisses being identical in age and origin. Some might be part of the substratum of the leptite formations.

II. YOUNGER ARCHAEAN.

Later than the above-mentioned Katarchaean rocks, and separated from them by an unconformity, is a second series of sedimentary rocks with intercalated sheets or beds of volcanic rocks and tuffs ranging from meta-quartz-trachytes to meta-basalts all cut by later granites. These rocks differ from the Katarchaean in almost everywhere retaining sufficient of their original characters for diagnostic purposes—for instance, the sediments are indisputably ordinary sediments—but they are generally metamorphosed to a considerable extent and strongly dislocated so that the dips are usually almost vertical, and they are frequently injected by granitic material, thus grading into migmatites. It will be seen that the younger Archaean of Fennoscandia is exactly analogous to Miller's Temiskamian (Huronian as defined by Logan), and if they occurred in Canada they would unhesitatingly be referred to as such.

In his typical area near Tampere (Tammerfors) Sederholm called them the Bothnian series. Here the sediments are metapelitic and psammitic rocks, greywackes and conglomerates. The mica-schists occasionally contain structures believed to be fossils, possibly algae, reminiscent of those in the Steep Rock Lake, Temiskamian rocks.

In Lapland, and on the Arctic Coast, quartzites and interbanded magnetic iron ore and quartzite or chert are conspicuous with the schists, conglomerates, and greenstones. Sederholm calls this the Lapponian series.

In eastern Finland his Ladogan series includes dolomitic limestones.

Here, as in Canada, the Younger Archaean came to a close through diastrophism and widespread granitic intrusion.

III.

Separated from the Younger Archaean, by a major unconformity, is a third cycle of sedimentation called Karelidic by Sederholm. Basal conglomerates, quartzitic sandstones, dolomite sometimes containing deposits of hematite, shales, and greenstones, the latter to a large extent intrusive, are found. The slates in places contain intercalations of schungitic coal. These rocks are normally much less metamorphosed than the preceding and very much resemble the Animikian rocks of North America.

But along certain lines diastrophism has acted, and granitic intrusions have ensued, metamorphosing the Karelidic rocks so that they may be locally difficult to distinguish from the older sediments.

IV. FOURTH CYCLE. LATE PRE-CAMBRIAN.

After the Karelidic, rocks were formed which preserve an almost entirely unmetamorphic character. It was a period of vulcanism and sedimentation. Rapakivi granites were injected forming necks, laccolith-like sheets, and effusive flows, upon the eroded surface of which sandstones were deposited into which basic eruptives (diabases, ossypites, labradorites) were injected, or through which the magma penetrated to cover them with surface flows.

In the Petsamon Tunturit range of Petsamo, on the Arctic coast of Finland, sedimentary rocks occur in small quantities associated with basic volcanics (pillow lavas) and ultra basic rocks (peridotites and serpentines). With the latter are hydrothermal deposits of nickel-bearing pyrrhotite and chalcopyrite that are of commercial interest. The position of these rocks in the Fourth Cycle has not been determined, but there is some reason for supposing they may be early. Occurrences of rocks of this cycle are scattered and exact correlations are not yet possible.

In Fennoscandia, as in America, the exact geological age of this Fourth Cycle is still problematical. While generally considered late pre-Cambrian, the possibility of its being early Cambrian is recognized.

It will be noted in the Comparative Table that Logan's Azoic and Sederholm's Archaeo-Progonic or Archaean are indistinguishable and that in the remainder the similarity is striking.

The chief differences are in Sederholm's meso- and neo-progonic. In the middle of the meso he has diastrophism and granitic eruptions, whereas in the Animikian only volcanic eruptions and a minor break have been recognized. Between the meso- and neo-progonic he considers the unconformity to be a great one, whereas the break between Animikian and Keweenawan is not considered a major unconformity. But it is to be remembered that the areas of these younger rocks in Fennoscandia are scattered and difficult to correlate

COMPARATIVE TABLE OF THE PRE-CAMBRIAN.

	Fennoscandia Sederholm's Classification		Nature of Rocks	Condition of Rocks	Logan's Classification		Miller's Classification
	V Cycle Lowest Part ?	Sparagmatian (" Hyperborean ")	Sediments				
Cambrian ? Neo-Progonic	Late Pre-Cambrian	Jotnian	Diabase dykes Sediments	Like Palaeozoics	Upper Copper-Bearing Series of Lake Superior	Upper Group Upper Portion	Keweenawan
	IV Cycle	Hoglandian	Gabbros and granites Basic lavas with interbedded conglomerates and sandstones	Rarely disturbed		Lower Portion	
	Great Unconformity					Disconformity or Unconformity	
? Meso-Progonic	Karelidic III Cycle	Dalslandian Post Jatulian epoch of diastrophism Kalevian and Jatulian	Arkoses and quartzites Granites, lavas Greywacke Quartzite Conglomerate	Generally unaltered and undisturbed		Lower Group	Animikee Upper Lower
	Great Unconformity					Great Unconformity	
(Archaean, Archaeozoic) Azoic Archaeo-Progonic	Younger Archaean	Post-Bothnian	Diabase dykes	Sometimes gneissoid	(Lower Copper-Bearing) Huronian		Matachewan
		Epoch of diastrophism	Granites			Huronian granite, syenite	Algoman
		Bothnian	Basic volcanics, dykes and sills	Somewhat metamorphosed		Huronian greenstones	Haileyburian
	II Cycle	Ladogan	Iron formation Argillite Quartzite Conglomerate	Schistose in part		Intrusive contact	Intrusive contact
		Lapponian		Highly disturbed High dips		Huronian sediments (Hastings series)	Temiskamian
	Great Unconformity					Great Unconformity	
	Katarchaean	Post-Svionic epoch of diastrophism	Gneissic Granites		Laurentian	Granite-gneiss	Granite-gneiss Intrusive contact
	I Cycle		Limestones Quartzites, argillites Iron formation	Highly metamorphosed Intricately folded and contorted		Grenville	Grenville
		Svionian	Volcanics				Keewatin Complex

[*To face p.* 138.

and that Fennoscandia has suffered from the Caledonian mountain-building, with its attendant igneous intrusion, and by the Hercynian as well. Without fossiliferous Palaeozoic rocks to determine the age of these later eruptives they may be placed in the later pre-Cambrian groups, thus complicating the apparent geological history. Recently Permian fossils have been found near Oslo that prove that plutonic rocks in this area are really Permian, making it probable that similar eruptives in Finland with attendant disturbances belong also at the end of the Palaeozoic. Sederholm warns us that " the adjoining classificatory table must be compared with statements in the text especially as to those parts of it that are still more or less hypothetical ". The rocks of the Canadian Shield, so far as is yet known, have not been folded or injected since pre-Cambrian times, and hence the pre-Cambrian history is easier to read with accuracy.

If the minor features, which are not necessary for the whole, be neglected, it will be seen that in these widely separated regions there are the same four well-separated principal groups or cycles with marked similarity in geological history in degrees of metamorphism and disturbance and even in the nature and composition of the rocks. The similarity in Archaean divisions is too obvious to mention. The sedimentaries of Cycle III are in both continental shelf deposits. There is a slight difference in the Fourth Cycle in that in America the lavas are terrestrial flows, as shown by their scoriaceous surfaces, and the sediments, too, are apparently terrestrial, suggested by the red colour and ill-sorted materials, whereas in Fennoscandia they appear to be water-lain, albeit shallow water deposits. The igneous rocks bear strong resemblances to each other. In fact, if one knows the pre-Cambrian, and pre-Cambrian history of either Fennoscandia or of the Canadian Shield, he has (if he only knew it) a fairly comprehensive and accurate knowledge of the pre-Cambrian of the other. If the same nomenclature were used for each he would at least suspect this, which would be of very great value to the geologist. In fact, a common nomenclature is essential. The multiplication of local names cannot be continued without ending in chaos. No one has the time to master them and their significance, and to fit them into their proper places in a general classification, nor, if he had the time, could he do so, for it can be done only by the man in the field. It is true a local name is not misleading, but neither is complete silence, which, except locally, is about as useful. A common term followed by a query is not misleading either, and it does what a local name cannot do, it shows the relationship of that member to other groups of rocks and about where the field-worker thinks it most probably belongs, and it calls for no feat of memory in masticating and digesting an uncouth new name, for each formation in each fresh district studied by a geologist.

The objection to employing the same nomenclature, of course, is that it implies correlations in geological time, and that in regions so far apart such correlations without fossils are considered impossible. Well, since everyone knows that, no one would be misled. He would enjoy the convenience without having to pay a tax.

But is it probable that the geological history is similar, except for widely differing geological ages of the great revolutions?

Fossil evidence has shown that there is a close correspondence in mountain-building in Palaeozoic times in Europe and America; careful palaeontological work is showing that the great revolutions that affected the western Cordillera of America were also periods of diastrophism on the other side of the Pacific; the Alpine movement was world-wide in extent; mountain building is at present going on all around the Pacific rim and along the equatorial earthquake belt. It is now apparent that there have been definite geological periods of world-wide mountain-building since Cambrian times, much more probable would be world-wide diastrophism in pre-Cambrian times, particularly in the earlier pre-Cambrian.

So far as the major divisions are concerned, a geological chronology based on diastrophism would be pretty much the same as our chronology based on palaeontology, for the periods of diastrophism cause the unconformities that give rise to the breaks in the life record. The classification of the pre-Cambrian of Logan, Miller, and Sederholm based on diastrophism and unconformities should be quite as accurate and as applicable to the pre-Cambrian as the corresponding classification of the post-Cambrian.

Let us boldly adopt it.

For nomenclature Logan's names should be used. This is in accordance with the rules of nomenclature, they have an historical value, and they are more widespread in the literature than any others. For the latter reason the terms in use in America for series not named by Logan are recommended.

The nomenclature recommended therefore is as follows:—

	Pre-Cambrian
Superian	Keweenawan Unconformity or disconformity Animikian
	Great Unconformity
Huronian	Huronian diabase dykes Huronian granites, etc. Huronian greenstones Temiskamian (Huronian sediments)
	Great Unconformity
Laurentian	Laurentian granite-gneiss Grenville Keewatin complex

With at least four cycles of sedimentaries, volcanics, and intrusives, with heavy erosion and hence many series missing or poorly represented that are necessary for correlation, it is obvious that in field work sufficient data will not always be obtainable to prevent uncertainties and mistakes in correlation. But the difficulties are lessened by the magnitude of the two great revolutions with their heavy igneous intrusions and of the resulting unconformities, and by the marked differences in the degrees of metamorphism of the groups as a whole. Further, it is a matter of experience that the keen observer, when his eye has been trained to a given region, can recognize subtle distinctive features by which distinctions and correlations may be shrewdly suspected, leading to the diligent, detailed search that is so frequently rewarded with success; again in a district that has suffered several revolutions one can recognize and distinguish even the several granites and their relative ages by their appearance, before he has secured any other and more determinative evidence.

The condition of pre-Cambrian geology is not wholly unsatisfactory. Much is definitely known, and much more knowledge is within reach—the chief trouble appears to be the lack of suitable terminology, properly and universally employed.

REVIEWS.

THE BOOK OF MINERALS. By A. C. HAWKINS. New York: Wiley and Sons; London: Chapman and Hall, 1935. pp. xii + 161. Price 7*s.* 6*d.*

THIS short book has been written for those, other than professed mineralogists, who "would like to learn something about minerals". Forty-four pages dealing with occurrence and properties are followed by a hundred pages devoted to the description of about one hundred and seventy species, and the information appears on the whole to be well selected and accurate. Formulae are given in the simpler cases (not in every instance correctly), and these seem somewhat arbitrarily chosen—whilst andalusite is described merely as "a silicate of aluminium", natrolite is allotted a formula occupying 3·8 cm. of print.

BRITISH REGIONAL GEOLOGY: NORTH WALES. By BERNARD SMITH and T. N. GEORGE. pp. vi + 92 with 12 plates and 30 text-figures. *Mem. Geol. Surv.*, 1935. Price 1*s.* 6*d.*

AS might be expected from the earlier volumes, there is much that is excellent in the present handbook as regards maps, sections, and photographs, but the balance of treatment so characteristic of the others is lacking in the present case, and the result is as a whole disappointing. No one wishes to detract from the splendid work of Ramsay in the region, but in view of the fact that Sedgwick was the first to undertake systematic work over the whole area, and devoted so much of his life to its elucidation, it is disappointing to find so little reference to some of the districts rendered classic by his labours. It is not that less is wanted about " Cambria " but that more, much more, is wanted concerning " Ordovicia "; or at any rate parity of treatment for both.

Reference to Greenly's great achievement in Anglesey naturally finds a place, but sufficient emphasis is not laid upon the fact that both in Anglesey, and on the mainland the basal Arenig conglomerates contain abundant fragments of Mona Complex rocks, a fact which has significance far beyond the confines of North Wales. It would have been fairer also to state that the section shown in fig. 6 represents only one possible interpretation of the Cambrian of North Wales, it is certainly not the only one, and is far from meeting with universal acceptance.

It is surely reasonable in these days also to expect some reference to the horizon of the Carboniferous rocks in terms of the accepted nomenclature, however much the palaeontologist may be able to interpret the facts for himself.

As regards the rest, there are three short, but very interesting chapters dealing respectively with the effects of the Hercynian earth movements in the region; the different types of evidence relating to the possibility of its having been covered by Mesozoic rocks; and the disposition of various peneplanes of different heights and ages.

In the final chapter the various problems connected with the glacial geology are clearly set out.

G. L. E.

Bristol and Gloucester District. By F. B. A. Welch and R. Crookall. pp. v + 89, with 12 plates and 27 text-figures. *Mem. Geol. Surv.*, 1935. Price 1*s*. 6*d*.

THIS handbook is one of the best that has been issued. From the early days of geology up to the present, the district has been classic ground owing to the work of many famous British geologists; if with all the resources at our command in these days it is possible to modify or amplify their conclusions, it should never be forgotten that the sound foundations were laid by them: De la Beche, John Phillips, and Ramsay belong to the earlier days, Buckman, Arthur Vaughan, Reynolds, Richardson, Tutcher, McMurtrie, and Arkell to more recent times, and as a result there is probably no district of its size and varied geology that has been more intensively studied; this is clearly indicated in the handbook where justice has been done to all so far as space has permitted.

With the exception of the Ordovician, rocks of all ages from the

Cambrian to the Cretaceous come to the surface within its bounds, but naturally some formations are of greater interest than others. The sections in the Lower Carboniferous have been made classic by the labours of Vaughan, whose work has been brought up to date by Reynolds. The Coal Measures are unique in our country as affording the highest workable coal seams and the relation of the lower beds in the series to those of other areas is given in terms of palaeobotany and the non-marine mollusca.

It is, however, permissible to wish that instead of the all too common and misleading statement " the Coal Measures were brought to a close by the great earth movements known as Armorican or Hercynian " there might be given a definite indication that these earth movements were in reality in active operation throughout Carboniferous time, and merely reached their culmination in the British Isles in post-Coal-Measure time.

After the Carboniferous the most interesting sections are those dealing with the Rhaetic and Jurassic rocks ; the Rhaetic here reaches its completest development within the British Isles, and its relation to the Lias is clearly brought out. The treatment of the Jurassic rocks follows much the lines adopted by Arkell in his book, the importance of Buckman's early work is duly stressed, and the extent to which the geological world is indebted to Linsdall Richardson is made fully evident.

Throughout the handbook, the subject matter is illustrated by numerous sections drawn for the most part from previously published papers, but there is a welcome and notable addition in the shape of numerous excellent vertical sections and some interesting and instructive block diagrams.

The photographs are up to the high standard we now expect in these publications.

G. L. E.

REPORTS AND PROCEEDINGS.

Mineralogical Society.

Thursday, 30th January, 1936.

(1) " The Morven meteorite, an aerolite from South Canterbury, New Zealand." By Mr. C. O. Hutton (communicated by Professor W. N. Benson).

This stone, which weighed about 7,100 grams before being broken, was found in 1925 during ploughing 4½ miles south of Morven railway station. There is no local record of the fall, and the nature of the weathered crust suggests that it may have been in the soil for a long time. Micro-sections are described and detailed chemical analyses were made of different fractions. The stone is classed as a veined and brecciated bronzite-olivine-chondrite containing 13·18 per cent of metallic nickel-iron. It is the fourth meteorite to be recorded from New Zealand.

(2) " Eulysites and related rock-types from Loch Duich, Ross-shire." By Professor C. E. Tilley.

Rocks of eulysitic facies referred to a sedimentary origin are recorded among paragneisses involved in the Lewisian near Loch Duich. They include varieties rich in manganfayalite, hedenbergite, iron-hypersthene, and garnet, and are associated with grunerite-garnet-magnetite rocks of related origin.

(3) " Gold and silver in the crystalline rocks of the Malvern Hills." By Professor A. Brammall and Mr. David L. Dowie.

Gold (traces up to 3 dwt./ton) and silver (traces up to 42 dwt./ton) are indicated by assay results for over 100 samples of mapped rock-types and their constituent minerals. The highest values are associated with a pneumatolytic phase of the " latest " granites. Assay data and spectrographs afford some check on the interpretation of certain mixed rocks, notably dioritic and appinitic types.

(4) " The rôle of Al-atoms in the two reaction series." By Professor A. Brammall.

X-ray work suggests that the break in the enstatite-diopside series and also that between the amphiboles and the basic micas is related to the continuous reaction (NaSi)-(CaAl) in the plagioclase series. The rôle of Al-atoms in the two series is reciprocal.

(5) " On the magnetite-plagioclase rocks of Magnet Heights, Bushveld, Transvaal." By Dr. A. K. Wells.

The paper describes the petrographic characters of the unique magnetite-plagioclase rocks which occur associated with norite and anorthosite at a relatively high level in the Bushveld complex. The bearing of the petrography upon the problem of the genesis of the rocks is discussed.

GEOLOGICAL SOCIETY OF LONDON.

The following awards of Medals and Funds have been made by the Council :—

The Wollaston Medal to Professor Gustaaf Adolf Frederik Molengraaff, of Delft.

The Murchison Medal to Mr. Ernest Edward Leslie Dixon, of H.M. Geological Survey.

A Lyell Medal to Mrs. Eleanor Mary Reid.

Another Lyell Medal to Professor Leonard Johnston Wills, of the University of Birmingham.

The Wollaston Fund to Dr. George Hoole Mitchell.

The Murchison Fund to Miss Emily Dix.

The Lyell Fund to Dr. Sidney William Wooldridge.

The following are the Officers for 1936. President, Professor O. T. Jones ; Vice-Presidents, Mr. J. F. N. Green, Professor H. L. Hawkins, Professor W. J. Pugh, Professor H. H. Swinnerton ; Secretaries, Professor W. T. Gordon, Dr. L. Hawkes ; Foreign Secretary, Sir A. Smith Woodward ; Treasurer, Mr. F. N. Ashcroft. New Members of Council, Professor C. G. Cullis, Mr. W. N. Edwards, Professor W. G. Fearnsides, and Dr. W. F. L. McLintock.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIII.

No. IV.—APRIL, 1936.

ORIGINAL ARTICLES.

Some Minor Intrusions of Glen Shee, Perthshire.

By W. O. WILLIAMSON, North Staffordshire Technical College, Stoke-on-Trent.

CONTENTS.

1. INTRODUCTION.
2. INTRUSIONS IN AND AROUND THE MAIN GRANODIORITE.
3. A "PORPHYRY" WITH "CLOUDED FELSPARS".
4. HYPABYSSAL ROCKS MARGINAL TO THE MAIN GRANODIORITE.
5. OTHER INTRUSIONS.
6. SUMMARY.
7. REFERENCES.

1. INTRODUCTION.

THE major intrusions of Glen Shee have been described (Williamson). These are :—

(1) The composite Duchray Hill Gneiss, produced by invasion of the Ben Lui Schist by oligoclase-quartz or andesine-quartz magma. This magma has united with the pelitic portion of the schist to give an oligoclase-(or andesine-)muscovite-biotite-gneiss bearing siliceous, lime-silicate, and Older Basic rocks, which had been avoided by the invading magma.

(2) The Newer Diorite. Most exposures of this " diorite " show a rock termed " the Main Granodiorite ". Partially digested fragments (" Basic Patches "), of what are almost certainly " Older Basic Rocks ", scattered through the granodiorite, testify to its contaminated origin. The granodiorite thermally altered, and suffered a further contamination by, the richly pelitic Duchray Hill Gneiss. This contamination, strictly marginal, gave rise to biotite-cordierite granodiorites carrying much unassimilated cordieritic hornfels.

The author, having no immediate opportunity for re-visiting Glen Shee, thought it desirable to publish such data as he had to hand concerning the hitherto undescribed minor intrusions of the area.

2. INTRUSIONS IN AND AROUND THE MAIN GRANODIORITE.

These comprise veins or dykes in the granodiorite itself, in the Ben Lawers Schist, and in the Contaminated Rocks adjacent to the Duchray Hill Gneiss. Apart from the quartz-veins which, when they occur in the Ben Lawers Schist, are doubtless indistinguishable in some instances from the segregation-veins of this formation, most of the intrusions are aplites and pegmatites, many of them preserving, in their deficient alkali-felspar, a characteristic of the Main Granodiorite.

Pinkish veins cut the Main Granodiorite and its "Basic Patches". They may be split centrally and bear pyrite or limonite after it, in the median fissure.[1] The veins are often below 1 inch across but may attain 18 inches. They contain oligoclase and andesine, quartz, and orthoclase, sometimes with a little biotite, hornblende, and diopsidic pyroxene. The minerals have little tendency to idiomorphism. In pegmatitic veins the quartz and orthoclase may be micrographically intergrown. One vein, 3 inches wide, is a granodiorite porphyry with phenocrysts of quartz, sericitized oligoclase or andesine, and chloritized biotite. Its fine-grained groundmass, apparently quartz and orthoclase, is obscured by sericitization and reddish iron-staining. A dyke of granodiorite porphyry is described later.

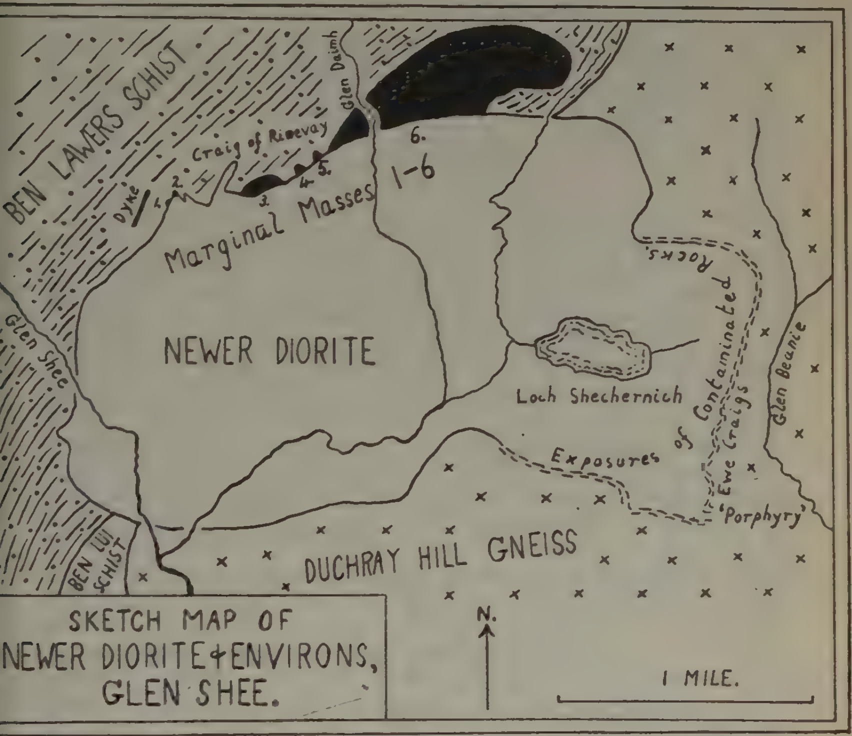
Aplites and pegmatites in the Ben Lawers Schist are usually less than 2 inches thick, and have oligoclase, andesine, orthoclase, and quartz, sometimes with biotite, hornblende, and diopsidic pyroxene. The pyroxene-bearing veins have been contaminated by certain Ben Lawers hornfelses (op. cit., p. 406). The nature and extent of reaction, if any, between other veins and their hosts is not easy to demonstrate. The biotitic selvedges bordering certain veins suggest some reaction. They are curiously sporadic and sometimes found on one side only of a vein. Fluids from the veins appear to have attacked the biotite, largely represented by chlorite bearing rutile-needles, and to have effected micaceous alteration of cordierite where present in the host. Such selvedges are noted, for example, between pegmatites of quartz and orthoclase, anhedral and slightly granophyric, and cordierite-andalusite-corundum-green spinel-hornfels. Pseudomorphs after cordierite in the pegmatites point to contamination of the latter by the hornfels.

That the Main Granodiorite could yield an alkali-rich residuum is revealed by those veins, e.g. the pegmatites just described, in and around this rock-mass, which consist essentially of alkali-felspar and quartz. This felspar is usually orthoclase, as in certain veins in the Ben Lawers Schist, which have margins of pink orthoclase and interiors of white quartz, the latter sometimes forming good crystals projecting into a central open fissure. In one (non-composite) vein the felspar is probably anorthoclase.

---

[1] Pyrite is the characteristic mineral of the "younger" intrusives of Glen Shee and is seen in and near them. Other metallic sulphides may accompany it. Thus traces of molybdenite occur in the joints of the Leucocratic Granodiorite (Williamson, p. 401) and of chalcopyrite in those of the Main Granodiorite.

Further evidence of the alkali-rich residuum seems to be afforded by a contact between Main Granodiorite and a Ben Lawers quartzite. The quartz-grains of the latter are now set poikilitically in plates of orthoclase. In the absence of the orthoclase the grains could be fitted together with some success. Apparently the Granodiorite caused the separation of the grains and provided an alkali-felspathic liquor which filled the resultant voids.



Text-fig. 1.—Adapted partly from Sheet 56 of the Geological Survey's 1 in. map of Scotland.

Other intrusions in the Ben Lawers Schist are dykes of biotite-granodiorite, not unlike the Leucocratic Granodiorite, possibly a dyke-rock, noticed elsewhere (op. cit., p. 401), e.g. the 5 ft. wide dyke on Craig of Rinevay, near Marginal Mass 1 (*vide* Text-fig. 1).

Small veins of biotite-granodiorite may run into the Ben Lawers Schist from either the Main Granodiorite or the biotite-granodiorite dykes.

Finally, veins among the Contaminated Rocks must be mentioned. These are aplites and pegmatites of quartz and orthoclase, sometimes graphically arranged in the pegmatites, with accessory biotite, muscovite, oligoclase, and andesine.

3. A "PORPHYRY" WITH "CLOUDED FELSPARS".

This interleaves aligned strips and lenticles of blue hornfels. It is found at the south-eastern extremity of the Newer Diorite, among the Contaminated Rocks, and is split by a puzzling narrow cleft (*vide* Text-fig. 1).

In the "porphyry" well-formed plagioclase, zoned approximately $Ab_{65}An_{35}$ to $Ab_{79}An_{21}$, is the most abundant phenocryst. The zoning is normal or resembles the oscillatory-normal zoning figured by Phemister (plate xxii, fig. 1). Brown biotite, and quartz, also have claims to be called phenocrysts but exhibit unusual characters. Biotite, often altered to green chlorite bearing rutile-needles, tends to give the peculiar ragged clots which characterize rocks contaminated by cordieritic hornfels (Williamson, p. 414). Concrete evidence of the contamination is afforded by the association of certain biotitic masses with patches of pinitized cordierite bearing green spinels.

Quartz is largely anhedral and has a tendency to form patches of contiguous grains, numbering up to a score of variously sized individuals. Frequently it moulds on the porphyritic plagioclase or patches of it enclose small, sometimes corroded-looking, plagioclases.

For the most "normal" porphyry the volume-percentages are of the order :—

Phenocrysts	Plagioclase	31
	Biotite (and chlorite)	13
	Quartz	4
Groundmass (and accessories)		52

The groundmass minerals, quartz and orthoclase, are granular and have an average diameter of 0·02 mm. They contrast strongly in size with the plagioclase phenocrysts (up to 3·5 × 1·4 mm.).

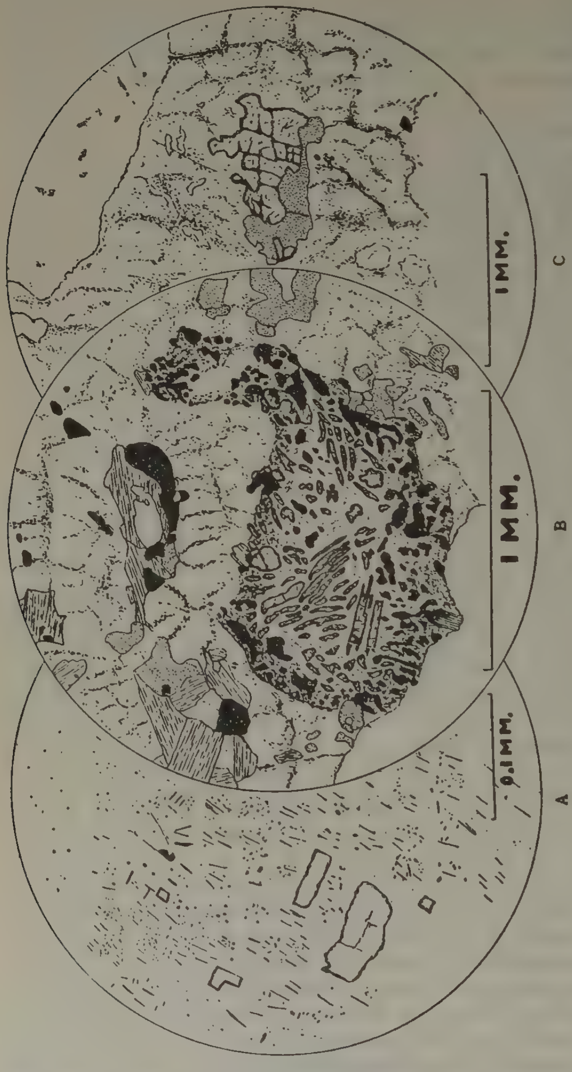
Accessories not previously mentioned are apatite (occasionally darkened by inclusions), zircon, sphene, rhombohedral carbonate, ilmenite, magnetite, and pyrite.

Near the hornfels-xenoliths, the porphyry develops plates of orthoclase and euhedral crystals of cordierite much altered to yellow chlorite and green mica. The xenoliths themselves include much greenish secondary mica, both as tiny flakes and as sheaves of laths showing cleavage, with relics of cordierite, andalusite, corundum, and green spinel. Thus the xenolithic hornfels is of the type derived from the mica-garnet bands of the oligoclase-muscovite-biotite-gneiss on metamorphism by the Newer Diorite (op. cit., pp. 410–11, 412). For the Contaminated Rocks it has been suggested (op. cit., p. 415) that, after the demonstrable thermal alteration of the above gneiss to alternating narrow layers of hornfels and quartz-felspar, the Main Granodiorite penetrated along the latter layers, dissolved, or preserved as xenocrysts, the quartz and felspar of these, and then proceeded to react with the neighbouring hornfels-strips. A similar explanation seems unavoidable for the present " porphyry ", i.e. the quartz and felspar of the original gneiss are represented in the " porphyry "-veins which form a complex with the hornfels.

Microscopic characters of the " phenocrystic " plagioclase of the " porphyry " suggest the presence of xenocrystic cores. The characters, not necessarily observable in one and the same " phenocryst ", comprise :—

(1) A cloudy interior and a narrow clear rim (apparently clear crystals may represent sections cutting only this rim). There is not always a compositional change at the junction of interior and rim. The cloudiness of the interior results from the presence of minute rods, with a few hairs. The rods, in densely clouded areas, may provide four sets of mutually parallel individuals, each set inclined to its neighbours. The crystallographic orientation of the rods has not been completely elucidated. Tiny specks appear also, of which some, but probably not all, are really cross-sections of rods (Text-fig. 2A). Rods, specks, and hairs are apparently opaque. They are, according to Macgregor, strong evidence of the re-heating of their felspar-host (Macgregor, especially description on pp. 525–6). Dr. H. H. Thomas noted felspars with cloudy centres appearing in the xenoliths held by the Trégastel-Ploumanac'h Granite (Thomas and Smith, p. 278 and plate xvii, fig. 3), and again, at Slieve Gullion, he ascribed clouding of felspars in basic rocks, and in xenoliths thereof, to the presence of later acid magma (Richey and Thomas, pp. 786 and 828). Similarly Anderson (p. 268), Deer (pp. 60–61), Gardiner and Reynolds (p. 15 and p. 14, fig. 2 (1)), Joplin (1933—though Macgregor's suggestion that " clouding " is an exosolution phenomenon is criticized—1935, p. 233), Tomkeieff and Marshall (p. 278), and Williamson (pp. 406, 414) mention occurrences of " clouded " felspars in situations compatible with " clouding " by thermal metamorphism. Nockolds, however, notices " numerous minute, almost opaque, rods and needles " in the plagioclase of the tonalites of Loch Awe (pp. 305, 311, 312, 316), but makes no comment on their origin. Moreover, Wiseman (p. 370) finds the " cloudiness " in albite (according to Macgregor, p. 536, not a common occurrence) in the Crinan district, where, he points out, igneous intrusions, other than epidiorites, are absent. Macgregor (p. 530), discussing " clouding " of felspar in the Scourie dykes,

does not, however, insist that it is due to heat derived from neighbouring magma; it may result from "regional heating



TEXT-FIG. 2.—Micro-structures of some minor intrusions of Glen Shee. A: Details of a "cloud" in plagioclase "phenocryst" of "porphyry" at south-eastern extremity of Newer Diorite. Opaque rods and specks are seen, and crudely rectangular areas of orthoclase (see text). These areas are bounded by the plagioclase-cleavages which appear also to determine the direction of some of the opaque rods. B: Xenolith from an aplite cutting Mass 3. Green spinels fringing skeletal mass of andalusite; the rest of the field is occupied by quartz, felspar, biotite, and iron-ores. C: Andalusite in contact with biotite, and associated with quartz and felspar, in Mass 6.

connected with depth". Whether such an explanation is applicable to the instances noted by Wiseman in low-grade epidiorites might be questioned.

(2) Transparent inclusions in the interior but not in the rim. These appear as many faintly pinkish areas, irregular, or forming crude parallelograms with their sides following the plagioclase-cleavages, and are believed to be orthoclase. Similar inclusions have been described previously (Williamson, pp. 400, 401, 402, 413, 414, fig. on p. 415). Judging from rock-slices examined, they are common in the oligoclase and andesine of granodiorites, tonalites, monzonites, and related plutonic rocks. The inclusions probably result from excretion of potash-felspar formerly held in solid solution in the surrounding plagioclase. Their apparent preference for oligoclase and andesine, as against more sodic or more calcic plagioclase, may possibly be correlated with the statements of Winchell (pp. 369, 371, 372, 374, 376, 378) that oligoclase and andesine contain up to 7 and 8 per cent $KAlSi_3O_8$ respectively, falling to 5 per cent in albite, and continuously through intervening plagioclases to 4 per cent in anorthite.

The present appearance of the inclusions would appear to have been facilitated by the re-heating of their host. This idea receives some confirmation from the decided increase in the number of such inclusions in the plagioclase of the oligoclase-muscovite-biotite-gneiss where the latter has been strongly metamorphosed by the Newer Diorite. The opaque inclusions mentioned under (1) do not, however, develop so readily. They have been noted only in the syntectic material believed to contain xenocrysts of "older" felspar, and are pronounced only when Main Granodiorite bulks largely in such material (Williamson, p. 414).

(3) A core delimited by a brownish streak. This streak runs roughly parallel to the exterior of the crystal or pursues a vaguely elliptical course unrelated to it. Iron-oxide and biotite are definitely identifiable in the streak, which probably corresponds to the iron-stained periphery of an "older granite" felspar (op. cit., pp. 388–9).

To assign the peculiarities noted under (1) and (2) to the re-heating of the "porphyry" as a whole by some later intrusion is unsupported by field or microscopic evidence.

The quartz of the "porphyry" shows no sure symptoms of a foreign origin, though certain quartzose patches may be xenoliths of the aggregated quartz-grains of the "older granite" (op. cit., p. 388).

The "porphyry" has its nearest analogue in the "rocks with little abnormality" (op. cit., p. 414), held to result from slight contamination of the Main Granodiorite. In these rocks, however, plagioclase phenocrysts are rare. In them Main Granodiorite is held to be the igneous component, but it is probable that an alkaline differentiate from the Granodiorite is involved in the "porphyry" and has insinuated itself into contact-altered oligoclase-muscovite-biotite-gneiss.

4. HYPABYSSAL ROCKS MARGINAL TO THE MAIN GRANODIORITE.

Their outcrops are indicated in Text-fig. 1 by the numbers (1)–(6). No outcrop shows the contact with the Main Granodiorite, while the contact with the Ben Lawers Schist is visible only on the west of mass (3).

Loose blocks suggest the presence of masses (1) and (4); mass (5) can be discovered with difficulty in the crags of Ben Lawers Schist on the west side of the entrance to Glen Daimh. Further discussion of these three masses is omitted.

Mass (2) shows pinkish-weathering blocks, with porphyritic quartz and felspar up to 5 mm. in diameter, situated at a higher level than exposures of Main Granodiorite which appear further down the south slope of Craig of Rinevay. In these exposures the Granodiorite is cut by a dyke 5 feet wide. A second parallel dyke is uncertainly indicated a few feet to the west.

The relations between the dykes and the marginal mass, and between the latter and the Granodiorite, are not clear. Probably the mass rests on the Granodiorite and was fed by the dykes.

Both major mass and 5 ft. dyke are granodiorite porphyries having frequent phenocrysts, usually ill-formed and often composite, of quartz, markedly sericitized oligoclase or andesine, and biotite. Much biotite is changed to chlorite containing needles and grains of rutile. The groundmass is of granular quartz and orthoclase. Rarely orthoclase attains porphyritic dimensions and is then sometimes minutely streaked with plagioclase (probably oligoclase). Apatite, zircon, ilmenite, magnetite, pyrite, and a white mica ("bleached" biotite ?) are among the accessories.

The marginal mass shows in the field pyrite, veins of white quartz, and a few xenoliths of Ben Lawers Schist up to 3 × 2 in. An enclave of Main Granodiorite, carrying a "Basic Patch", was obtained from it and is evidence that, as previously stated, the porphyry is younger than the Granodiorite.

A sliced xenolith of Ben Lawers Schist is fine-grained and contains masses and strings of brown very fresh lath-shaped or blebby biotite associated with irregularly sized units of oligoclase or andesine. Some sericitic patches, suggesting former cordierite, enclose rare green spinels. One or two spinels appear in fresh material which may be cordierite. There is much dust-like or granular unaltered black iron-ore.

Ben Lawers hornfelses, comparable with the above xenolith, are found in the aureole of the Main Granodiorite.

Mass (3) comprises two porphyritic igneous rocks and many xenoliths of Ben Lawers Schist. The igneous rocks are:—

(*a*) A granodiorite-porphyry. This is a pinkish-weathering rock similar to the example just described. It is cut by aplites and bears pyrite on its joint-planes. Phenocrysts are of quartz, zoned oligoclase and andesine, biotite, and scarce green hornblende. The biotite is altering to chlorite with sphene and rutile. There is a groundmass of quartz and orthoclase, granular, or with occasional micrographic intergrowth. Epidote, apatite, zircon, ilmenite, magnetite, and pyrite are also present, with some sericite and calcite. One slice contains a clot (cognate xenolith ?), about 4 mm. across, of ragged intergrown laths of brown biotite and green hornblende, dotted with ilmenite-grains.

An aplite cutting the rock bears an interesting xenolith. This aplite shows anhedra of quartz and orthoclase, with some zoned oligoclase, sometimes subhedral. There are frequent flakes of chloritizing biotite. The xenolith is of skeletal andalusite fringed by units of green spinel and rare magnetite (Text-fig. 2B). The spinels are enclosed by sericite and associate with some greenish biotite. Their location suggests a reaction-rim, rather than spinel indigenous to the xenolith. If this surmise be correct, one is reminded of the marginal enrichment in spinel apparent in certain aluminous xenoliths from Mull and South Africa (Thomas, p. 241 ; Hall and Nel, especially diag. on p. 5), though the encompassing rock, tholeiite and anorthosite respectively, is very different from that of the present xenolith. It is not contended that the processes operative in the genesis of the spinel here noticed are identical with those believed, by the authors concerned, to have functioned in Mull and South Africa. In the hollows of the andalusite-skeleton are clear grains, probably of cordierite. Elsewhere in the aplite, fine-grained biotitic patches, and aggregates of small-sized biotites carrying tiny green spinels, suggest relics of similar xenoliths (cf. Williamson, p. 415, fig. 12A).

(*b*) A quartz-felsite. This shows crystals of quartz and felspar in a pink aphanitic groundmass. Both minerals are allotriomorphic. The felspar is orthoclase enclosing oligoclase as streaks or grains. The groundmass is a mosaic of quartz, orthoclase, and oligoclase. Grouped small brown biotites are rare. Greenish micaceous pseudomorphs resembling pinite associate with or are separate from them. Ill-formed colourless garnets with prominent cracks are frequent, and one example is inserted in a biotitic group. The heavy residues show much garnet, appearing pale red-brown, considerable colourless andalusite, and abundant magnetite.

During a traverse northwards, from a point south of the eastern portion of mass (3), Main Granodiorite, granodiorite porphyry (described under (*a*)), and quartz-felsite (described under (*b*)), are passed successively. The mutual relations of the rocks are obscure. In the western portion of the mass quartz-felsite alone is exposed, intimately veining and carrying many xenoliths of Ben Lawers Schist. The igneous and metamorphic rocks are deeply stained with limonite and hematite and contain much pyrite. The igneous rock resembles the quartz-felsite previously described (the description is based on rocks from the east of the mass), but carries undoubted chloritized cordierite. The xenoliths include silica-poor cordierite-andalusite-corundum-hornfelses and silica-rich hornfelses of numerous quartz-grains, contiguous or separated by small areas of sericitized felspar, of which at least some is oligoclase and andesine. Certain of the felspathic areas are accompanied by ragged colourless garnets. The presence of such hornfelses raises the possibility that the andalusite and garnet of the quartz-felsite are, as the cordierite doubtless is, the result of contamination. Better examples of similar hornfelses may be found in place nearby, though here, for the garnetiferous type, zoisite predominates over garnet.

From incidental references in this and in an earlier paper (op. cit) it will be realized that the Ben Lawers Schist provides, against the Newer Diorite and marginal masses, an interesting and varied series of hornfelses. The principal hornfelses are mentioned in these references, but a detailed study of the contact-metamorphism of the Schist is hampered by the difficulty of following individual layers of rock into the thermal aureole; especially as variation in the chemical composition of the Schist is sometimes very rapid, e.g. silica-rich and silica-poor hornfelses may appear even in the limits of a single thin section (op. cit., p. 404).

Mass (6) is indicated, incorrectly, on Sheet 56 by G (= granite). Exposures, though inadequate, show quartz-felsite containing andalusite and relics of cordierite, or with drastic chemical or mechanical alteration. The quartz-felsite may be classified thus :—

(1) The unaltered rock is pinkish and bears phenocrysts of quartz and orthoclase, both ill-formed and often composite, in a groundmass of granular quartz and orthoclase. Grains exist intermediate in size between phenocrysts and groundmass. Occasional oligoclase and andesine appear in the groundmass or as phenocrysts. There are a few flakes of brown biotite. Allotriomorphic andalusite, which may show a faint pinkish pleochroism, touches biotite (Text-fig. 2c) or is unassociated with it. Contamination is further suggested by chloritic pseudomorphs, sometimes with form, after cordierite. There is a general resemblance to the andalusite-bearing quartz-felsite of mass (3).

(2) The first sign of mechanical post-solidification alteration of the quartz-felsite is provided by fractures, filled by quartz, cutting groundmass and phenocrysts. In the intensely altered rock the phenocrysts have broken down to groups of angular separating fragments, with bent and faulted twin-lamellae where plagioclase is present, in a fine-grained base. White mica and chlorite after biotite are found.

(3) The chemically altered quartz-felsite has phenocrysts of glassy quartz in a white compact groundmass bearing patchy red stains of hematite. Felspar, both as phenocrysts and in the groundmass, has been replaced by white mica, to give what is essentially a quartz-muscovite rock.

In short, the three marginal masses described comprise granodiorite porphyry and quartz-felsite. The granodiorite porphyry of mass (2) is later than the Main Granodiorite. In mass (3) similar porphyry associates in an uncertain field-relation with quartz-felsite and this quartz-felsite resembles the unaltered rock of mass (6). Thus, if the test of similarity is reliable, the granodiorite of mass (3), and possibly the quartz-felsites of (3) and (6), also post-date the Granodiorite. The granodiorite porphyries of (2) and (3) would then, as shown by the nature and amount of their minerals, be petrogenetically related to the basified intrusion (Main Granodiorite) which they border. On the other hand, the mechanical and chemical alteration of (6) might be effects of the intrusion of the Granodiorite, and the andalusite and cordierite of (3) and (6) be ascribed to contact-metamorphism. To the same cause might be due the marked crenulation against the groundmass of the phenocrysts of the quartz-felsites (cf. the outline of the biotite and andalusite in Text-fig. 2c). However, masses (2) and (3) have Ben Lawers xenoliths. In (2) there is no suggestion of contamination by such xenoliths, but in (3) andalusite and cordierite appear in conjunction with aluminous enclaves. Thus the cordierite is likely to be a product of contaminaton. Andalusite, and perhaps garnet, may be similar products. For (6), in which no xenoliths were recognized, the presence of andalusite and cordierite is evidence for a contaminated rock.

All that can be said at present is: The granodiorite porphyry of mass (2) is later than the Main Granodiorite, while that of mass (3) is presumptively so; the quartz-felsites of masses (3) and (6) are of uncertain age.

5. OTHER INTRUSIONS.

The unsheared dykes and sills not obviously associated with the Newer Diorite are among the worst exposed rocks of Glen Shee. Often neither their contacts with their country-rocks nor their dimensions are discernible. None of the intrusions has been found to cut the Newer Diorite. It is uncertain whether the intrusions are older or younger than the Diorite, or whether both "pre-Diorite" and "post-Diorite" members are present.

The intrusions include lamprophyres of several types, and rocks bearing porphyritic quartz and felspar (orthoclase and/or oligoclase and andesine) with chloritized biotite, in a quartz-orthoclase groundmass. Pyrite, ubiquitous in the "younger" intrusions of Glen Shee, appears in both porphyritic and lamprophyric rocks.

Certain of the intrusions mapped on Sheet 56 are no longer traceable. On the other hand, dykes have been discovered not there marked, e.g. a lamprophyre at the north end of Ewe Craigs, near a south-facing gneiss-like assemblage. This assemblage comprises contact-altered oligoclase-muscovite-biotite-gneiss, bearing quartzites, semipelitic granulites, and calcareous granulites, associated with pinkish pegmatite and slightly contaminated Main Granodiorite (cf. the contaminated rocks described by Williamson, p. 414). This lamprophyre, judging from its lack of thermal alteration, is later than the Newer Diorite. It consists of close-packed orthoclase-laths, with marginal red-brown staining, having some interstitial quartz and carbonate. There are patches of chlorite, which associate with a few relics of greenish hornblende. Ilmenite, pyrite, and innumerable acicular apatites are the chief accessories.

A lamprophyre from the east dyke on Meall Odhar (*vide* Sheet 56) has ragged phenocrysts of biotite, showing pronounced dark margins in the more basal sections, in a groundmass which is well-nigh indecipherable, including biotite and chlorite flecks, sphene (or leucoxene), carbonate, and decomposed felspar (some is andesine). Green actinolite-like amphibole occurs, sometimes as needles projecting into quartzose areas. Prismatic apatites, up to 1·25 mm. long, are abundant.

A lamprophyre of yet a third type cuts the Ben Eagach Black Schist of Coire Bad an Loin. On Sheet 56 it is shown crossing a stream (unnamed) three-quarters of a mile north of Kerrow. In the lamprophyre laths and plates of felspar (orthoclase, albite-oligoclase, and oligoclase) associate with quartz, diopsidic pyroxene, brown hornblende, and chlorite after biotite. The hornblende may be intergrown with, or stand in reaction-relation to, the pyroxene. Alternatively crystals of it may border greenish-yellow serpentine which pseudomorphs the pyroxene.

6. SUMMARY.

Some additional data are given regarding the "newer" intrusions of an area of which the main petrological features have been described elsewhere. The intrusions are :—

(1) Aplites, pegmatites, quartz-veins, granodiorite porphyries, and biotite-granodiorites in or around the Newer Diorite.

(2) A "porphyry" contaminated by cordieritic hornfels and having "clouded" plagioclase "phenocrysts". Evidence is given that the "phenocrysts" have xenocrystic cores.

(3) Quartz-felsites with cordierite, andalusite, and garnet, and granodiorite-porphyries, lying between the Newer Diorite and its roof of Ben Lawers Schist. The granodiorite-porphyries post-date the Diorite but the age of the quartz-felsites is uncertain. Contamination, and mechanical and chemical alteration, of the quartz-felsites are recorded.

(4) Newer quartz-felspar-porphyries and lamprophyres, not obviously associated with the Newer Diorite.

7. References.

Anderson, J. G. C., 1935. "The Arrochar Intrusive Complex," Geol. Mag., LXXII, 263–283.

Deer, W. A., 1935. "The Cairnsmore of Carsphairn Igneous Complex," *Quart. Journ. Geol. Soc.*, xci, 47–76.

Gardiner, C. I., and Reynolds, S. H., 1932. "The Loch Doon 'Granite' Area, Galloway," *Quart. Journ. Geol. Soc.*, lxxxviii, 1–34.

Hall, A. L., and Nel, L. T., 1926. "On an Occurrence of Corundum-Sillimanite Rock in the Norite of the Bushveld Igneous Complex, West of Lydenburg," *Trans. Geol. Soc. S. Africa*, xxix, 1–16.

Joplin, G. A., 1933. "The Petrology of the Hartley District. II," *Proc. Linn. Soc., N.S.W.*, lviii, 125–158.

—— 1935. "A Note on the Origin of Basic Xenoliths in Plutonic Rocks, with special reference to their Grain-size," Geol. Mag., LXXII, 227–234.

MacGregor, A. G., 1931. "Clouded Felspars and Thermal Metamorphism," *Min. Mag.*, xxii, 524–538.

Nockolds, S. R., 1934. "The Contaminated Tonalites of Loch Awe, Argyll," *Quart. Journ. Geol. Soc.*, xc, 302–321.

Phemister, J., 1934. "Zoning in Plagioclase Felspar," *Min. Mag.*, xxiii, 541–555.

Richey, J. E., and Thomas, H. H., 1932. "The Tertiary Ring Complex of Slieve Gullion (Ireland)," *Quart. Journ. Geol. Soc.*, lxxxviii, 776–849.

Thomas, H. H., 1922. "On Certain Xenolithic Tertiary Minor Intrusions in the Island of Mull (Argyllshire)," *Quart. Journ. Geol. Soc.*, lxxviii, 229–260.

—— and Smith, W. C., 1932. "Xenoliths of Igneous Origin in the Trégastel-Ploumanac'h Granite, Côtes du Nord, France," *Quart. Journ. Geol. Soc.*, lxxxviii, 274–296.

Tomkeieff, S. I., and Marshall, C. E., 1935. "The Mourne Dyke Swarm," *Quart. Journ. Geol. Soc.*, xci, 251–292.

Williamson, W. O., 1935. "The Composite Gneiss and Contaminated Granodiorite of Glen Shee, Perthshire," *Quart. Journ. Geol. Soc.*, xci, 382–422.

Winchell, A. N., 1933. *Elements of Optical Mineralogy*, part ii, New York.

Wiseman, J. D. H., 1934. "The Central and South-West Highland Epidiorites: a Study in Progressive Metamorphism." *Quart. Journ. Geol. Soc.*, xc, 354–417.

On the Structures of the Dermal Ethmoid Shield of Osteolepis.

By T. Stanley Westoll, University College, London.

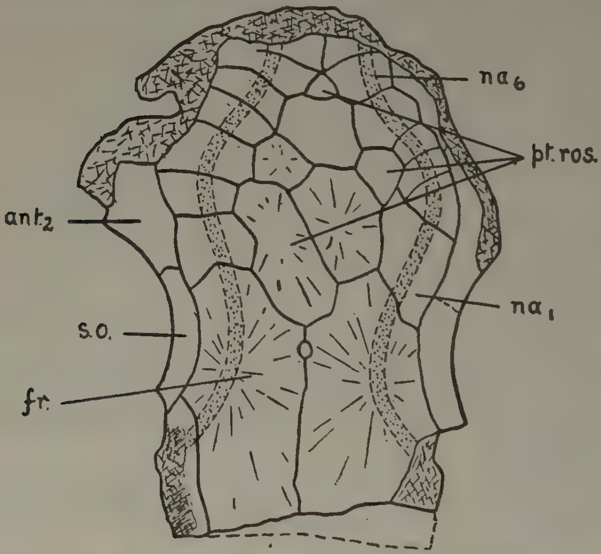
(PLATES I and II.)

I. Introduction.

THE Rhipidistian fish *Osteolepis macrolepidotus* Ag. has been the subject of a very extensive literature: the latest and most complete account is that of Säve-Söderbergh (1933), to which reference may be made for an account of the history of previous investigations. (It may be mentioned here for the sake of completeness that a drawing of the skull of *Osteolepis* by Watson is given in Swinnerton (1923), fig. 247: this figure is not mentioned by Säve-Söderbergh.)

The material described by Säve-Söderbergh is all from the Sandwick fish-bed at Sandwick, Mainland, Orkney Islands. In these specimens, separate bones cannot be distinguished in external view over the anterior part of the "fronto-ethmoid shield", as this region is covered by a continuous sheet of shiny cosmine.

In a few specimens from Tynet Burn, however, it is possible to see much of the structure of this region in specimens which are seen from the inside of the dermal shield, or are otherwise suitably prepared. These allow a nearly complete description of the region to be offered; the purpose of this paper is firstly to place on record a standard of comparison for *Megalichthys* and other Rhipidistia to be described in forthcoming papers, and secondly to draw attention to some peculiar problems of the mode of growth in the Rhipidistia and Dipnoi, and to offer a suggestion for their solution.



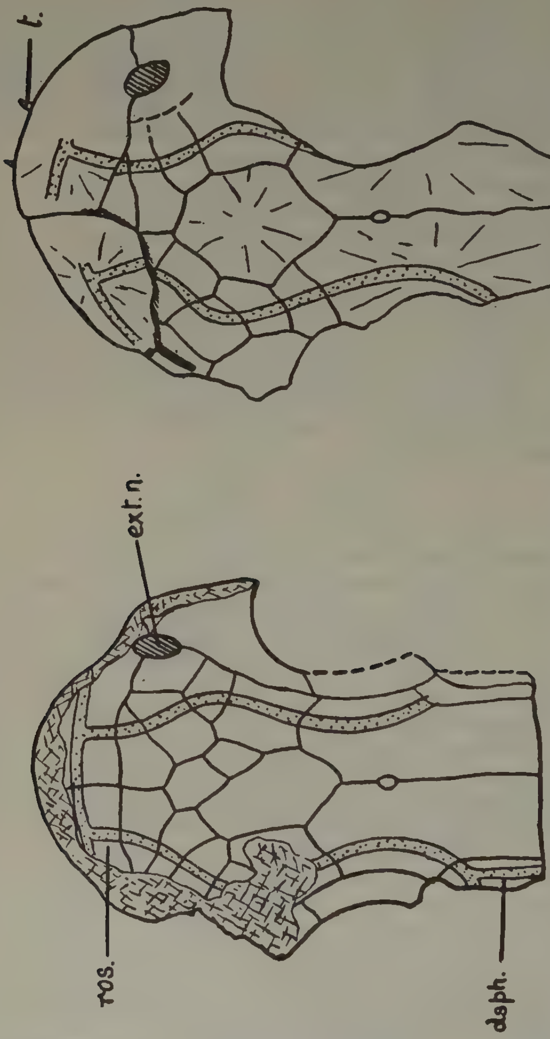
TEXT-FIG. 1.—Dermal bones of the fronto-ethmoidal shield of *Osteolepis macrolepidotus*, Tynet Burn. Professor Watson's coll., U.C.L., P. 87. × 5. Key to lettering used in figures: ant.I., anterior antorbital; ant.2, posterior antorbital; cos., cosmine covering snout; dsph., dermosphenotic; e.sc., extrascapulars; eth.c., ethmoidal commissure; ext.n., external nostril; fr., frontal; i.t., inter-temporal; ju., jugal; la., lacrimal; na., nasal; pa., parietal; p.o., post-orbital; pt.ros., post-rostral; ros., dentigerous rostral or premaxillary; s.o., supraorbital; s.t., supratemporal; t., teeth. The sensory canals are stippled.

It gives me great pleasure to acknowledge the kindness of those in charge of the geological collections in the museums of Aberdeen University, Elgin, and Inverness, in allowing me to study material of *Osteolepis* in their care : of Dr. A. C. Stephen, who has allowed me to work over the fine collections at the Royal Scottish Museum : and of several gentlemen connected with other museums in Scotland, in which I searched for Tynet Burn *Osteolepis* showing the skull. Mr. C. Forster Cooper, of the University Museum of Zoology, Cambridge, has allowed me to use freely the magnificent collection of *Dipterus* which he has made at Achanarras, which provided me with much interesting information regarding the growth of cosmine-clad fishes. Dr. W. D. Lang and Dr. E. I. White have been most kind in allowing me to study the magnificent collections in the British Museum (Natural History), and Dr. White has discussed several points with me. Professor D. M. S. Watson has been most interested in this work from the start and has allowed me to use his own remarkable collection at University College, London : it is impossible adequately to acknowledge the value of his enthusiastic and constant help and criticism. Finally, I am indebted to the Department of Scientific and Industrial Research for a Senior Research Award.

II. Description of Material.

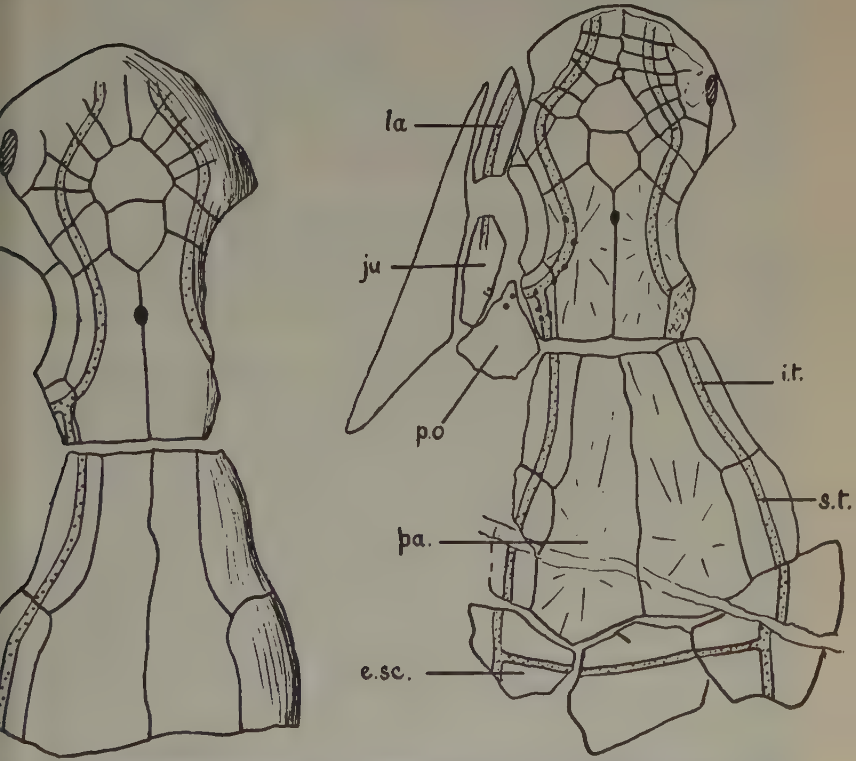
A Tynet Burn *Osteolepis macrolepidotus* in Professor D. M. S. Watson's collection at University College (no. P. 87) shows the dermal bones of the fronto-ethmoid shield from within (Text-fig. 1). The curvature of the shield near its anterior margin is very considerable, and the most anterior and lateral parts are missing. The supraorbital sensory canals are very well shown, passing forwards in a sigmoid flexure which appears to be characteristic of the Rhipidistia. Posteriorly, a little less than half the length of the canals is enclosed in the frontals, which are bones of quite familiar shape, including the pineal foramen between their anterior parts. The supraorbitals and dermosphenotics are not very well shown. The anterior part of each supraorbital canal traverses a series of small bones—the nasals. These number six on each side. The sensory canals pass forwards, apparently into a pair of transversely broadened bones—the rostrals. The space between the nasals and frontals is occupied by an irregular and asymmetrical series of six bones, the " post-rostrals ". Probably owing to the strong curvature of the nasal series, one of the left nasals (the second from the frontal) is excluded from contact with the post-rostrals.

The supraorbital is continued forward on each side by a bone which becomes rapidly wider anteriorly and forms the anterior margin of the orbit. This is the posterior antorbital. It is in contact with at least the first two nasals on each side. The nostrils are not preserved, but lateral to the nasal series and in front of the left posterior antorbital there is some evidence of one or two small bones.



TEXT-FIG. 2.—A. Dermal bones of fronto-ethmoid shield of *O. macrolepidotus*, Tynet Burn. Internal view. × 4. Author's coll. B. Squeeze of specimen from which the dermal bones have been partly removed. × 3. Yorkshire Museum.

A specimen from Tynet Burn in the author's collection shows a rather good fronto-ethmoid shield (Text-fig. 2A), also from within. The frontals are quite normal, and the nasal series is again quite well marked. The first nasal on each side in advance of the frontals is rather large, and the second is excluded from the post-rostrals. There are five nasals on the right, four on the left. There are three post-rostrals. The posterior antorbital of the left side is fairly well preserved, and appears to form the postero-lateral margin of the external nostril. The supraorbital sensory canal on each side passes anteriorly into a transversely wide bone, in which it anastomoses with a transverse canal—the ethmoid commissure. The bone concerned is the rostral; it forms the anterior margin of the external nostril, the mesial margin of which is formed by a small bone touching the nasals, which may be termed " the anterior antorbital ", following Säve-Söderbergh.



Text-fig. 3.—A. Skull-roof of *O. macrolepidotus* from Tynet Burn, dermal bones removed leaving sharp mould. × 9/2. Inverness Museum. B. Internal view of head-bones of *O. macrolepidotus*, from Tynet Burn. × 4. Author's coll.

A specimen from Tynet Burn in the York Museum allows the structure to be further elucidated. The dermal bones are largely removed, but are indicated by moulds of their internal faces on the crystalline calcite filling the dermal shield (Text-fig. 2B). Squeezes allow the structure to be made out in part. The nasal series is incomplete, but probably consists of five bones on each side, though the right rostral has been disturbed. There is a single post-rostral, and apparently a single " anterior antorbital " bone. The rostrals show the anastomosis of the supraorbital canal with the ethmoid commissure, and the left rostral can be seen to bear teeth: in fact, it forms the oral margin of the shield.

A fish in Inverness Museum (No. 9) shows a remarkably sharp mould of the internal surface of the dermal bones (Text-fig. 3A). There is nothing unusual about frontals, dermosphenotics, supraorbitals and posterior antorbitals, and the nasal series is only remarkable in displaying such a well-marked radial arrangement. There are six nasals on each side. The left nostril is well shown, and there seems to be only a single anterior antorbital bone. There are two post-rostrals.

A small skull of *Osteolepis macrolepidotus* from Tynet in the author's collection shows a remarkably fine view of the interior of the skull (Text-fig. 3B). The only points of present interest are the very complete series of nasals—seven on the left, six on the right side—and the existence of probably more than one " anterior antorbital ". There are four post-rostrals.

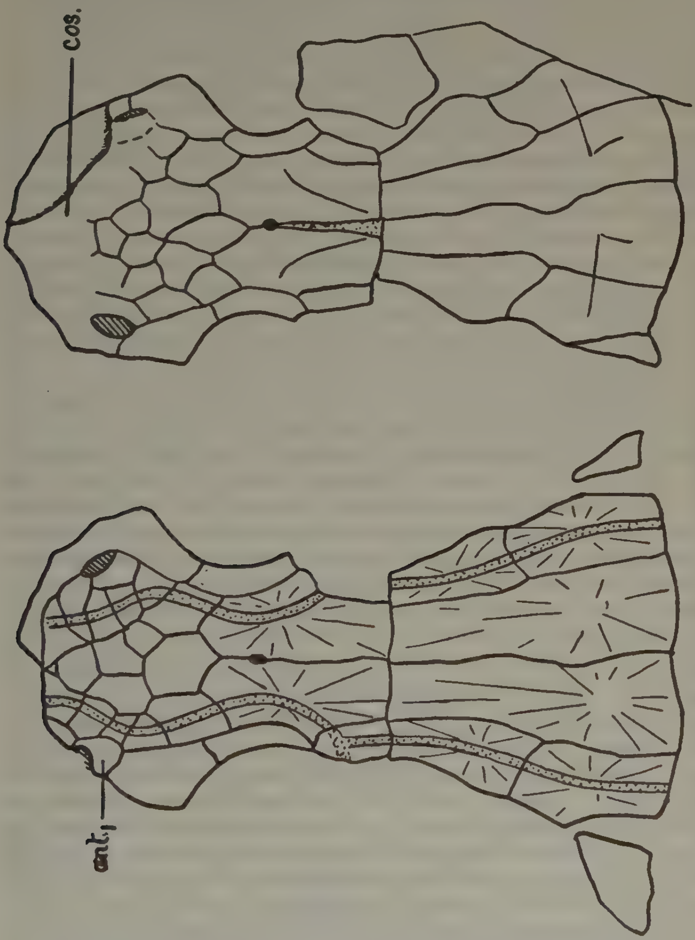
A small specimen from Tynet Burn in the Royal Scottish Museum (1884, 60.3) shows all but the oral border of the ethmoid skull very well indeed, again in internal view (Text-fig. 4A). There are six nasals on the left, five on the right side, while the " post-rostrals " number six. The nostrils are well-shown, and are bounded posteromesially by a small bone, the anterior antorbital. The rest of the structure will be clear from the figure.

It is usually only in specimens from nodules that one can make out much of the structure of the ethmoid region of *Osteolepis*. However, P. 3340 (Brit. Mus. Nat. His.) shows the impression of the external surface of an extremely fine skull of *Osteolepis macrolepidotus* from the Orkneys (Text-fig. 4B). It shows no details in the extreme anterior region, where the cosmine coating is continuous, but shows three nasals on each side, six post-rostrals, and traces of a single " anterior antorbital ". The posterior antorbitals are extremely well shown, and each nostril is shown to be enclosed by posterior antorbitals, anterior antorbitals, and rostral.

There are small but constant differences in proportion between the " *Osteolepis macrolepidotus* " material from Tynet Burn and Orkney, and they are almost certainly true specific differences; nevertheless the structural plan is identical so far as can be seen, and the differences do not invalidate the general arguments of this paper.

Most of the above-mentioned structures have been observed on numerous other specimens in addition to those figured. Several of the Orkney specimens figured by Säve-Söderbergh (1933) are of interest :—

Pl. 1 ; almost continuous cosmine, traces of several post-rostrals.
Pl. 4 ; post-rostrals numerous and irregular.



4.—A. Internal view of skull-roof of *O. macrolepidotus*, Tynet Burn. × 3·5. Royal Scottish Museum, 1884. 60.3.
B. Squeeze of external mould of *O. macrolepidotus*, Orkneys. × 2·4. B.M.N.H., P. 3340.

Pl. 9, fig. 2, text-fig. 6 ; shows three post-rostrals, and a fine series of nasals : probably six on the right (third from back excluded from post-rostrals), and four shown on the left, but there may be another, excluded from the post-rostrals. The plate labelled " Ptr. 1 " is a nasal.

III. The Homology of the Bones.

The general plan of the snout of *Osteolepis* is easily condensed from the above account. The supraorbital sensory canals pass anteriorly from the *frontals* in a sigmoidally curved course through a series of *nasals*, rather variable in number (4–7). They then pass into a pair of bones forming the oral margin and bearing teeth: in these bones, which have been called *rostrals* above, they anastomose with the ethmoidal commissure of the infraorbital canals. Between the nasal series and the frontals is an extremely variable set of "*post-rostrals*", numbering in different specimens from one to six. The posterior nasals of each side are bounded by a bone which forms the anterior margin of the orbit, meeting the supraorbital behind and extending to the posterior margin of the external nostril, lateral to which it meets the rostral; this bone is the *posterior antorbital.* Lateral to the middle of the nasal series is a small bone (occasionally more than one) forming the posteromesial margin of the external nostril. These we may recognize as equivalent to the *anterior antorbital* of Säve-Söderbergh (1932, p. 75, also Stensiö, 1922, p. 1248, fig. 3).

This general arrangement of the frontal and nasal series can be paralleled in all the other Rhipidistia with the detailed structure of which I am acquainted—e.g. *Eusthenopteron* (Säve-Söderbergh, 1933, pl. 16), *Dictyonosteus* (Stensiö, 1922, p. 1248, fig. 3), *Diplopterax*, *Megalichthys*, etc. (author's unpublished observations). There is now general agreement that the bones related to the anterior parts of the supraorbital sensory canals are, at least in part, homologous with the tetrapod nasal. It is of great interest to consider the variation in number of the nasal series in *Osteolepis*. This can perhaps best be understood by assuming that, in the development of *Osteolepis*, a large number (seven or possibly more) of rudiments of dermal bones made their appearance, each related to a sensory-canal organ of the supraorbital canal. Pehrson (1923) found this to be the case in *Amia calva*, and he found that adjacent rudiments often tended to fuse at an early stage, while occasionally there would be no separate rudiment under one or more organs, ossification spreading from adjacent areas. By such processes it is very easy to explain the specimens which show less than seven nasals. It is also possible (though there is no definite evidence in *Osteolepis macrolepidotus*) that the more posterior members of the "nasal series" may be incorporated in the frontals: *Megalichthys* provides good evidence for this, as well as for the assertion that the frontals of Rhipidistia are formed in connection with several latero-sensory organs (author's unpublished work). This demonstrates the impossibility of drawing a sharp line between *frontals* and *nasals.* It is also possible, of course, that there may be occasional variation in the number of latero-sensory organs, though as a result of certain other unpublished investigations this is not thought an important factor in the variability of the nasal series.

The transverse bones at the front of the snout carry the ethmoid commissure, so that there is no doubt that they include representatives of the *rostral* series. It is just as obvious, however, that they correspond in every essential feature with the premaxillary bones of many Stegocephalia, which are also associated with the ethmoid commissure : these bones in Stegocephalia are undoubtedly the homologues of the mammalian premaxillaries. Both these facts were realized by Säve-Söderbergh (1932, p. 73 ; 1935 throughout) in the case of primitive Tetrapods, and he suggested that the bones in question should be called " rostro-premaxillaries ". Such a compound name, however, ought to imply the product of fusion of two sets of rudiments, and in this case is not necessarily justified. In no Rhipidistian or primitive Tetrapod known to the writer is there any indication, even as an abnormality, of the existence of two separate bones in this region. Moy-Thomas (1934) showed that the teeth of all the bony fishes he investigated were formed separately from the bones which afterwards bear them ; so that teeth could easily become attached to a lateral-line bone developed in the near neighbourhood, without the formation of separate tooth-bearing rudiments. The tooth-bearing lateral-line bones in *Polypterus*, *Lepidosteus*, etc., can easily be interpreted in this way, without using compound names for which there is no embryological evidence. Certain unpublished work by Mr. F. J. Aumonier on the development of *Lepidosteus* seems to confirm this suggestion in the case of that fish at least.[1] A bone in the position of a premaxillary, traversed by the ethmoid commissure and often bearing teeth, is found in most, if not all, the Palaeozoic Palaeoniscids which the writer has examined in detail (even, apparently, in *Cheirolepis*—but see Watson, 1925). This bone is certainly in part homologous with the tooth-bearing bone of *Osteolepis*, which is the homologue of the mammalian *premaxillary*, but which may be called the *dentigerous rostral* in the logical system based on the lateral-line bones. The latter name will be used for the present in order to avoid confusion with the " premaxillary " of the higher bony fishes, which may coexist with a separate ethmoid or rostral bone connected with the ethmoid commissure, and of which the full significance is not yet certain.

The " post-rostrals " are extremely variable in number, and somewhat variable also in extent ; however, the composite figure of Säve-Söderbergh (1933, text-fig. 12, p. 74), showing all his specimens reduced to the same length and superposed, shows that the post-rostrals occupy a well-marked area. The extreme variability of these bones prevents any attempt to trace individual homologies, and it seems certain that the space between the nasals was filled in each individual ontogeny in a haphazard manner. Such a process appears to have been widespread in the Rhipidistia, Dipnoi, etc., as will be shown in later papers, and occurs also in the living sturgeon. Bones occupying such areas may be conveniently termed *anamestic*[1] bones, and the writer believes that they merely exist as space fillers, and that their importance will vary according to the space available. They almost certainly have no genetical importance, and may disappear entirely: thus the "post-rostrals" of Rhipidistia may be expected to be reduced if the snout is narrow, or if the nasals are larger (as in *Megalichthys*). For these reasons it seems unwise to search for their homologues in Tetrapods, and to give long and unwieldy compound names to bones in this region in Stegocephalia (as in Säve-Söderbergh, 1932, 1935), for which there is not the slightest evidence of a compound origin.

---

[1] I am greatly indebted to my friend Mr. Aumonier for allowing me to make use of this information.

The bones termed *anterior* and *posterior antorbitals* in the above account are certainly the homologues of those in *Dictyonosteus* (Stensiö, 1922) and primitive Tetrapods (Säve-Söderbergh, 1932, 1935). The full importance of these bones will be brought out when work on *Diplopterax*, *Megalichthys*, etc., is published.

In the above analysis, the homology of the frontals has been avoided, as the writer will show in another place that the frontals and nasals of an *Osteolepis* include the homologues of nasals, frontals, *and parietals* of Tetrapods. The author's views on homologies are thus fundamentally contrasted with those of Säve-Söderbergh (1933, 1935), as will be shown by a thorough analysis of his nomenclature in this forthcoming paper.

IV. THE GROWTH OF THE FRONTO-ETHMOID SHIELD.

The dermal ethmoid shield has a very interesting structure. There is a series of separate bones, built of isopedin and cancellar layers, covered by a sheet of cosmine with a shiny surface. In this upper layer there is often no trace of separate bones, particularly in the most anterior parts. This cosmine layer is fixed to the underlying bones, and provides an interesting example of the differentiation of the cosmine (= fused placoid denticles of Goodrich, 1908, pp. 455 et seq.), from the subjacent bony plates (isopedin + cancellar layer).

It is not at all easy to understand the method of growth of a complex continuous curved sheet of cosmine fixed to a series of separate bony plates, themselves growing, and it seems only possible through some process of resorption and reformation. It seems quite impossible to do this in any but two ways: by resorption along the common surface, with sliding; or by more or less complete resorption of the cosmine, at least along the sutures, at intervals. Of these the former involves also intensive dispersed interstitial adjustment in the cosmine-sheet, and is rather improbable. It can be shown that the more sweeping resorption and redeposition, however, is of great importance in the Rhipidistia and primitive Dipnoi, and the recognition of this process leads to interesting and unexpected changes in taxonomy.

---

[1] From ἀνάμεστος filled up.

Osteolepis macrolepidotus rarely shows stages in this process; but in collections from several localities (Tynet, Gamrie, Orkney) there are a number of specimens of "*Gyroptychius macrolepidotus* Ag.", which correspond in every detail of structure with *Osteolepis macrolepidotus* except that the outer layer of cosmine has disappeared, leaving a dull ornamented surface on the scales and head-bones (Pl. II, Text-fig. 1); the bones of the ethmoid region are frequently scattered. The intermediate stages show greater or less areas of shiny cosmine, with rounded edges, on scales and bones bearing the "*Gyroptychius*" ornament. Such specimens are not to be confused with others in which the scales are split or weathered since the fracture of the nodule, and show the reticular structure of the cancellar layer. In a few specimens of *Osteolepis* with shiny cosmine there are blister-like areas which may be small relics of older cosmine surrounded by newly deposited material.

Diplopterax agassizi (Traill) provides more complete evidence of a similar change. The large "*Gyroptychius augustus* M'Coy" has the same body-form, structure, and position of fins and size of squamation as *D. agassizi* from the same locality. (There are local differences between *Diplopterax* from various localities, which will be described more fully in another place.) In addition the dermal bones of the skull have the same highly characteristic shape and relations in both types, and the bones of the ethmoid shield are separate in the "*Gyroptychius*". There are again occasional "blisters" on the shiny cosmine of *Diploterax*.[1]

The fish found so abundantly at South Head, Wick, referred to by Traquair, with some hesitation, to the genus *Thursius* (Traquair, 1888, p. 516) shows further details of this change. All stages between a "*Thursius*" with complete shiny cosmine and a fish with a perfectly typical "*Gyroptychius*" ornament can be observed. The resorption begins at the margins of the scales and certain head-bones, and intermediate stages show rounded patches of shiny cosmine in the central regions of "*Gyroptychius*" scales and bones.

Megalichthys shows the effects of resorption of quite thick layers of cosmine, again proceeding from the margins of scales and head-bones. Frequently only small tubercles of shiny cosmine are left in the central regions, and they may entirely disappear. In a few specimens, small areas, like these worn remnants, form " blisters " in a continuous cosmine-sheet which is regarded as the newly deposited material. In the individuals showing resorption, small specimens become indistinguishable from fishes usually labelled *Rhizodopsis* and large specimens have the characters of *Rhomboptychius*, which has long been recognized as synonymous with *Megalichthys* (e.g. Smith Woodward, 1891, p. 378).

---

[1] The fishes from Orkney figured by McCoy (1855) under the names of *Diplopterax agassizi* (pl. 2*c*, fig. 1), *Gyroptychius diplopteroides* (pl. 2*c*, fig. 3), and *Gyroptychius angustus* (pl. 2*c*, fig 2) form a fine series showing progressive loss of cosmine. The first shows cosmine on all scales and bones except the cleithrum, the second shows rounded cosmine relics, and the third has no cosmine at all.

Similar evidence is afforded by a few other Rhipidistia, some of which are yet undescribed. The present account is no more than a preliminary notice of an interesting phenomenon, which will be further developed in future papers on other Rhipidistia.

From the details of the appearance of the material mentioned above it is perfectly clear that the resorption cannot be, in many cases, due to mechanical or chemical weathering of the fossil; but whether or not the process of resorption herein suggested is real, certain Rhipidistia are found in very different guises, the range of variation transgressing the accepted boundaries between various genera and between the " families " Osteolepidae and Rhizodontidae. This observation will be of great value in re-study of the Rhipidistia now being undertaken by Dr. Säve-Söderbergh and myself.

Continuous sheets of shiny cosmine overlying separate isopedin bones are found in other parts of the Osteolepid skull. The mandible can be studied in *Osteolepis* and *Diplopterax* from Tynet Burn, Gamrie, etc., and the external sheathing dermal bones can be seen to consist of a dentary bearing teeth, and four " infradentaries " (supra-angular, angular, post-splenial, and splenial) bearing the mandibular sensory canal, all covered by a continuous sheet of cosmine. The problem of the growth of this complex structure is just as acute as that of the snout, and is susceptible to the same solution.

The parietal, supratemporal, and intertemporal bones may be welded in various ways and to varying extents by continuous shiny cosmine, as in *Diplopterax*, *Thursius*, and *Osteolepis microlepidotus* (very common). The bones of the cheek are also liable to be covered by continuous cosmine, particularly the squamosal and quadratojugal. This is undoubtedly the reason for the disagreement between various authors on the subject of the existence of a separate quadratojugal in *Osteolepis*.

It is an important fact that the resorption occurs all over the body at about the same time, so that it seems possible that it may have been due to some release of secretions. This process was almost certainly periodic, and the dermal bones of some *Diplopterax* from Tynet show traces of periodical growth in the form of concentric markings in the isopedin. A full-sized *Diplopterax* shows about five or six such rings.

It is a matter of great interest that the same process can be traced in *Dipterus*. The following account is based almost entirely on the collections made at Achanarras by Mr. C. Forster Cooper, who has been most kind in allowing me to see the collections and to make use of a yet unpublished paper. In this paper Mr. Forster Cooper has recognized at Achanarras two species of *Dipterus*, *D. valenciennesi* Sedg. and Murch., and *D. platycephalus* Ag. The latter differs from *D. valenciennesi* in the following characters, but is otherwise indistinguishable :—

D. platycephalus has a fully ossified snout, absent in *D. valenciennesi* ; has a thick cosmine layer with a shiny surface, absent in *D. valenciennesi* ; is usually larger than *D. valenciennesi*, though there is considerable overlap in size ; and has occasionally an ossified vertebral column.

It will not be necessary to discuss these points at all fully, as a more complete account is to be published elsewhere. The snout of *D. platycephalus* consists of a cosmine layer overlying extremely spongy cancellar bone, there being no isopedin. The isopedin-bones of *D. platycephalus* are precisely the same in extent as those of *D. valenciennesi*.

The cosmine on the head-bones and scales show the same resorption from the margins as was observed in the Rhipidistia, but the process seems to have been usually less drastic than in those fishes, as a comparatively large proportion of specimens show considerable relics of cosmine (see Pl. II, Text-fig. 2). The contours of these residual patches are very roughly concentric with the edges of the scale or bone, but are characteristically irregular. They are very closely similar to the irregularly concentric grooves, sometimes more than one, often observed on the cosmine of the dermal bones and scales of *D. platycephalus*, and it is not unreasonable to suppose that such grooves represent the stadia of past resorptions. This point is strongly in favour of a periodic resorption-deposition process.

From the evidence provided by this examination of *Dipterus* it seems that shiny cosmine is only found preserved in animals of greater than *c.* 20 cm. long. In a young animal a cosmine coating of the head-bones and snout would have to be reabsorbed frequently because of the rapid growth, while as the rate of linear growth was reduced with increasing size it would become possible to retain a cosmine coat for some time. Thus the possession of a strongly developed cosmine layer in large *D. platycephalus* is likely to be due to the slow growth-rate of the large fish, not to specific difference. In a few large specimens with cosmine largely resorbed there is a confused and amorphous mass in front of the true bones of the skull-roof, which the author believes to be a partly resorbed snout. The very spongy bone beneath the cosmine could be made loose and spicular by comparatively slight vascular resorption, so that growth would be quite possible.

The presence of an ossified axial skeleton in *D. platycephalus* is likely to be merely a function of size. As a result of this short analysis it is probable that the two "species" are really indistinguishable.

Similar shiny cosmine, associated with a "*platycephalus*" snout, is found in *Dipnorhynchus süssmilchi* (Eth. fils) (see Hills, 1933); in this fish there are also concentric grooves, probably representing resorption-stadia, on the cosmine-covered dermal bones.

The fact that resorption takes place in bones and scales where it is not necessary for growth is of considerable interest, as it suggests that the process depends on some chemical action probably due to the release of an internal secretion. Morphologically the resorption is equivalent to the shedding of placoid denticles or teeth.

The rhythmic nature of the cosmine resorption and redeposition is evidence that the growth was also rhythmic; the concentric growth lines on the inner face of the bones in some specimens of *Diplopterax* and *Osteolepis* show that this was so. Consideration of the conditions of deposition of the Caithness Old Red Sandstone leads to the conclusion that rainfall was probably, almost certainly, seasonal, and this offers a physical basis for a seasonal growth.

V. SUMMARY.

The structure of the fronto-ethmoid shield of *Osteolepis macrolepidotus* Ag. is described fully for the first time, and the homology of the dermal bones is discussed. The most interesting feature is the recognition of the existence of a sensory-canal bone bearing teeth in the position of the premaxillary of Tetrapods, with which it is shown to be homologous; the nomenclature of the equivalent bones suggested by Säve-Söderbergh is discussed and revised.

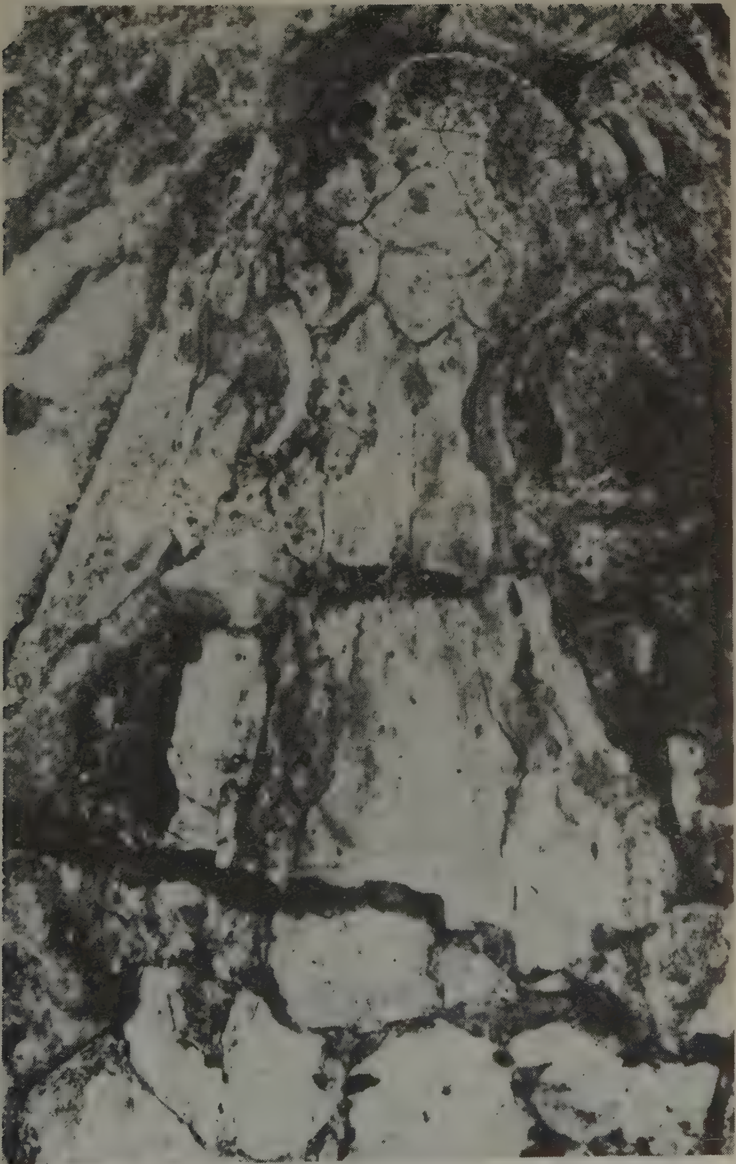
The presence of a continuous cosmine sheet overlying several bones is emphasized, and the problem of growth of such a combination is brought out. It is shown that the problem can be solved by extensive resorption and redeposition of cosmine, and this hitherto unnoticed change is demonstrated in a number of Osteolepids and in some Dipnoi. The results of the resorption are to free the bones of the head from the cosmine, and thus to expose the top of the true bone; the new characters are those usually associated with different genera, usually placed in distinct families.

Finally it is noted that the resorption involves a general chemical change affecting cosmine all over the body, which it is suggested may be due to the release of an internal secretion, the whole process of resorption and redeposition of cosmine being cyclic and almost certainly seasonal, growth being therefore a seasonal change.

BIBLIOGRAPHY.

FORSTER COOPER, C. (In the press) *Dipterus* from Achanarras.

GOODRICH, E. S., 1908. "On the Scales of Fish," *Proc. Zool. Soc. Lond.*, 1907, p. 751.



T.S.W. *Photo.*

OSTEOLEPIS MACROLEPIDOTUS

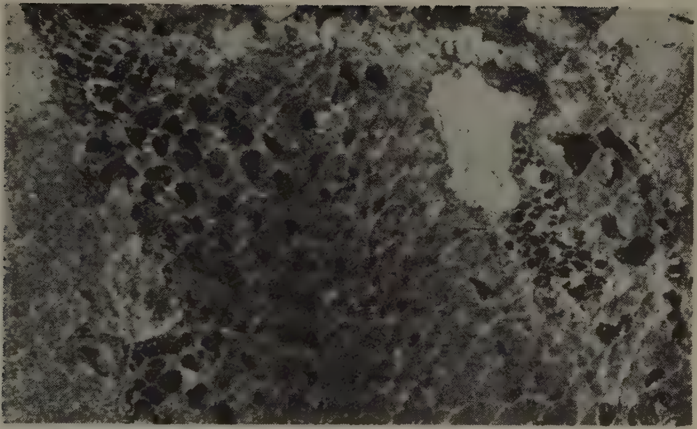


Fig. 2.

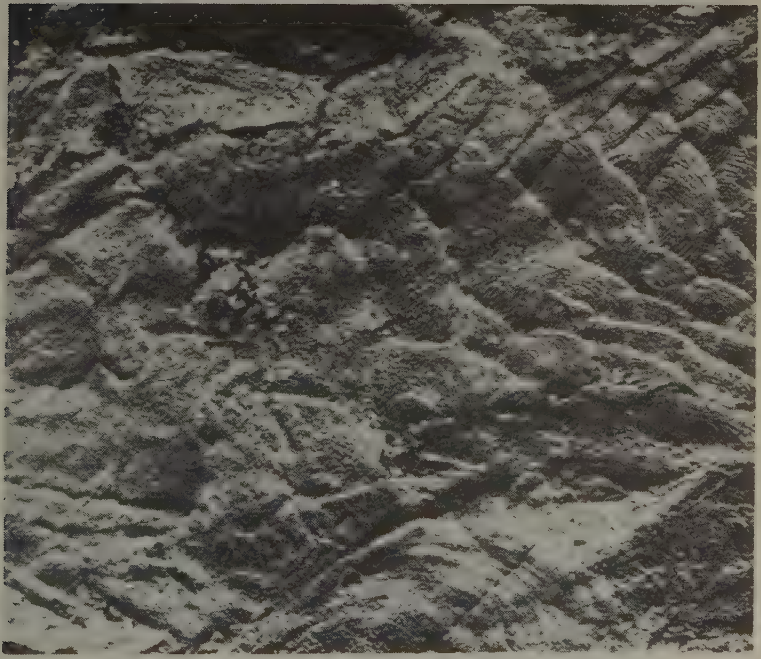


Fig. 1.

T.S.W. *Photo.*

Osteolepis and Dipterus

HILLS, E. S., 1933. "On a primitive Dipnoan from the Middle Devonian Rocks of New South Wales," *Ann. Mag. Nat. Hist.* (10), xi, p. 634.

McCOY, F., 1855. *Systematic Description of British Palaeozoic Fossils*, in Sedgwick and McCoy, *The British Palaeozoic Rocks and Fossils*, London.

MOY-THOMAS, J. A., 1934. "On the Teeth of the larval *Belone vulgaris*, and the attachment of Teeth in Fishes," *Quart. Journ. Microsc. Sci.*, 76, p. 481.

PEHRSON, T., 1922. "Some Points in the Cranial Development of Teleostomian Fishes," *Acta Zoologica*, Bd 3, p. 1.

SÄVE-SÖDERBERGH, G., 1932. "Preliminary Note on Devonian Stegocephalians from East Greenland," *Medd. om Grönland*, 94, No. 7.

—— 1933. "The dermal bones of the head and the lateral-line system in *Osteolepis macrolepidotus* Ag., etc.". *Nov. Act. Reg. Soc. Scient. Upsaliensis* (iv), 9, No. 2.

—— 1935. "On the Dermal Bones of the Head in Labyrinthodont Stegocephalians and Primitive Reptilia, etc.," *Medd. om Grönland*, 98, no. 3.

STENSIÖ, E. A., 1922. "Notes on certain Crossopterygians," *Proc. Zool. Soc. Lond.*, 1922, 1241.

SWINNERTON, H. H., 1923. *Outlines of Palaeontology*, London (another edition, 1930).

TRAQUAIR, R. H., 1888. "Notes on the Nomenclature of the Fishes of the Old Red Sandstone of Great Britain," GEOL. MAG., 516.

WATSON, D. M. S., 1925. "The Structure of Certain Palaeoniscids, and the relationship of that group with other Bony Fish," *Proc. Zool. Soc. Lond.*, 1925, 815.

WOODWARD, A. SMITH, 1891: *Catalogue of Fossil Fishes*, part ii, British Mus. (Nat. Hist.).

EXPLANATION OF PLATES I AND II.

PLATE I.—Untouched photograph of specimen of *O. macrolepidotus* shown in Text-fig. 3B. × 6.

PLATE II.—Fig. 1. Posterior part of skull-roof, extrascapular series and dorsal scales of a "*Gyroptychius*", showing the nature of the ornament of the bones and scales of *Osteolepis macrolepidotus* when the cosmine is removed. × 4. Yorkshire Museum.

Fig. 2. Cosmine resorption on the flank-scales of Dipterus. There is no cosmine left on the scales of the middle of the flank, but rounded relics are left on the dorsal scales and on the scale-covered lobe of the pelvic fin (below) and the posterior dorsal fin (top right). × 1. Dept. Zoology, Cambridge.

A Xenolithic Pegmatite in the Dalbeattie "Granite".

By MALCOLM MACGREGOR, University College, London.

I. INTRODUCTION.

A PEGMATITE containing numerous xenoliths of more basic rock was recently encountered in the "granite" quarry at Craignair, Dalbeattie, Kirkcudbrightshire. This rock merits description both on account of its unusual character and for the light which it throws on the interaction of a magma and xenoliths.

The actual site of the rock had unfortunately been obscured by subsequent blasting operations, but an examination of the large blocks which were available left no doubt that the pegmatite formed an irregular vein with a maximum width of about 4 feet. Xenoliths of more basic material are extraordinarily abundant in the rock. They are generally rounded and tend to have their longer axes parallel to the sides of the vein as if oriented by flow. Intruded into the pegmatite is an aplite which is free from xenoliths.

II. PETROGRAPHY.

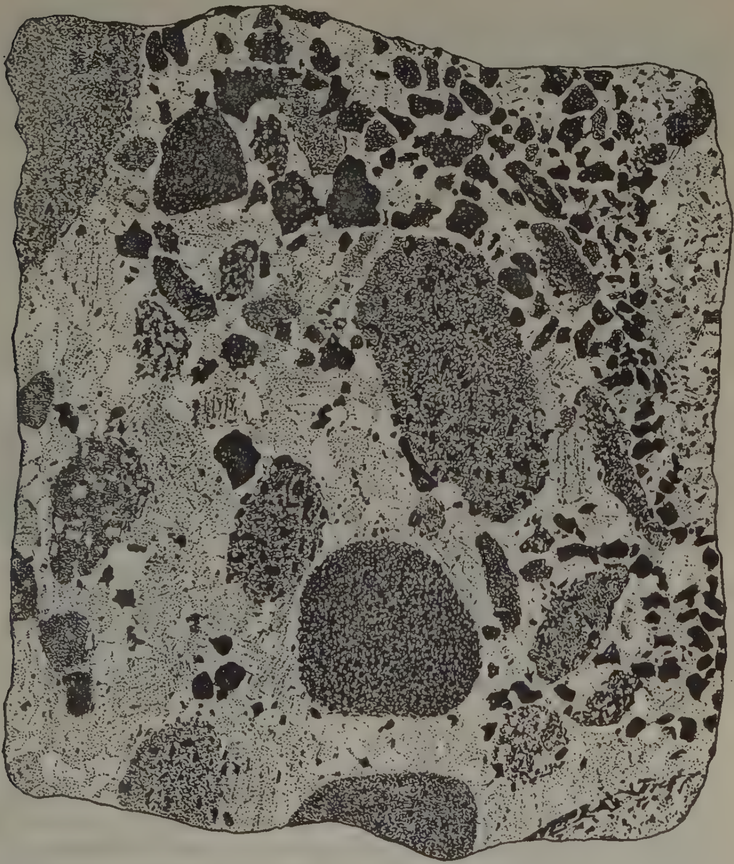
(a) *The Granodiorite.*

This rock, widely known as " Dalbeattie Granite ", was described by Teall (1896, pp. 41–2). It is a medium-grained grey granodiorite which shows a slight tendency towards the clotting of the ferromagnesian minerals.

In thin section it is seen to consist of plagioclase, microperthite, quartz, biotite, and hornblende, with sphene, apatite, iron ores, and zircon as the most important accessory minerals. The texture is monzonitic. Plagioclase is oligoclase/andesine and averages about $Ab_{75}An_{25}$. Zoning is usually well developed and involves layers varying in composition from Ab_{85} to Ab_{65}.[1] The crystals are normally more anorthic centrally but oscillatory zoning is common as reported by Teall (1896, p. 41). Twinning takes place on the albite, carlsbad, and pericline laws. Crystals are often turbid in the centre or in certain zones, but generally have clear margins which approach albite in composition at the extreme edge as recorded by Nockolds (1932, p. 436). Where plagioclase is in contact with microperthite it is corroded and a narrow zone of myrmekitic intergrowth with quartz has been formed. Microperthite is interstitial and encloses crystals of all the other minerals, especially small corroded crystals of plagioclase with myrmekite sheaths. It was the last mineral to crystallize, even quartz being euhedral towards it. It is an orthoclase-microperthite with $-2V = 64°$, and its extinction angles indicate that it is almost pure potash felspar (Alling, 1921, p. 231). The perthitic texture is on a small scale, and no twinning has been observed in the plagioclase wisps. Quartz is also interstitial. It contains lines of dust particles or bubbles and is generally strained. Biotite occurs as ragged crystals with strong pleochroism from dark chocolate brown to pale straw and has inclusions of apatite and iron ore. Hornblende is a brown-green pleochroic variety. $Z > Y > X$, Z = green-brown, Y = yellowish-green, X = pale yellowish-green, $\gamma \wedge c = 17°$, $-2V = 66°$, properties which indicate one of the common hornblendes. The crystals are rarely well formed and are often partly converted to biotite. Sphene is abundant as large euhedral crystals of typical lozenge shape, and small crystals of apatite occur throughout the rock. The dark clots are due to concentration of biotite and hornblende crystals with which are associated sphene and apatite.

---

[1] Plagioclase determinations have been made with the aid of the Federow stage by the " zonal method " of Rittmann.

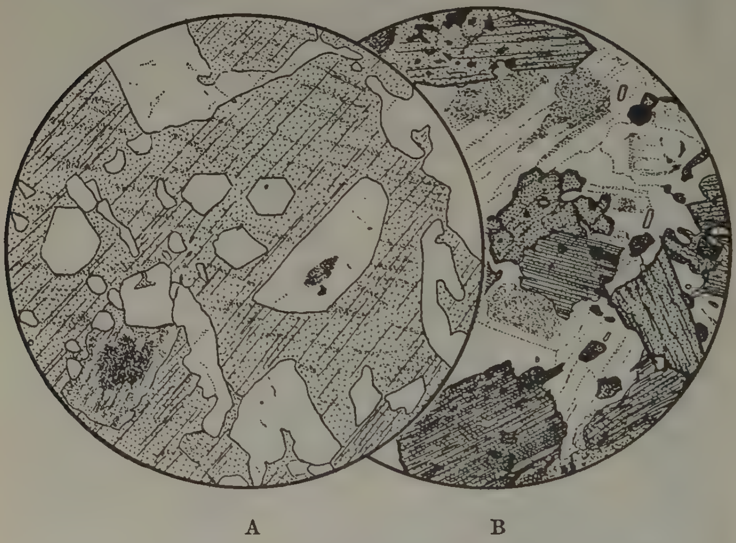


Text-fig. 1.—Drawing of polished surface of xenolithic pegmatite. Size 8½ × 7 inches. Showing dioritic xenoliths and concentration of holomafic xenoliths against granodiorite at the right.

The percentage by volume of the more important minerals shows considerable variation in different parts of the rock but averages: quartz 22·4, microperthite 20·7, plagioclase 46·9, hornblende 1·6, biotite 6·3, sphene 1·0, iron ore (ilmenite) 0·6, and apatite 0·5 per cent.

(*b*) *The Pegmatite.*

This rock contains xenoliths of more basic rock which account for about 50 per cent of its volume (Text-fig. 1). It is a leucocratic rock of rather coarse grain and consists of quartz and microperthite with a little albite. Sections, however, generally contain a small quantity of oligoclase, biotite, hornblende, and sphene which are considered to be xenomorphic, resulting from the disintegration of xenoliths. The texture is determined by large crystals of microperthite enclosing quartz poikilitically (Text-fig. 2A). The quartz crystals are occasionally in crystallographic continuity and there is a tendency towards intergrowth of the two minerals. The potash felspar is an orthoclase-microperthite with $-2V = 75°$ and from its extinction angles probably contains about 20 per cent of the albite molecule. It has well marked perthitic structure. The albite layers show twinning and have a composition of about $Ab_{98}An_2$. Albite also occurs as small clear anhedral crystals between the microperthite crystals, and there are a few large corroded crystals of oligoclase, about $Ab_{85}An_{15}$, which are zoned and have myrmekitic borders. The biotite and hornblende are similar to those minerals in the granodiorite.



Text-fig. 2.—A: Pegmatite (× 25). B: Dioritic xenolith. No. 2076 (× 25).

A micrometric analysis of a sample of pegmatite, as free as possible from xenolithic material, gives the following percentages of minerals by volume: microperthite 62·2, quartz 28·2, plagioclase (excluding layers in microperthite) 8·9, biotite, hornblende, and sphene 0·7 per cent.

The magma represented by the pegmatite is thought to have been a squeeze-out of residual liquid from a lower level in the granodiorite where crystallization was incomplete. The ratio of quartz and felspar approximates to the eutectic (Clarke, 1924, p. 304), a fact also suggested by the partial intergrowth texture.

(*c*) *The Aplite.*

This is a fine-grained light coloured rock consisting of plagioclase, microperthite, and quartz, with small quantities of biotite and apatite. The plagioclase occurs as small (average 0·2 mm.) subhedral crystals enclosed by larger crystals of quartz and microperthite. Its composition is acid oligoclase varying from about $Ab_{89}An_{20}$ to $Ab_{88}An_{12}$, the crystals being zoned and more basic centrally. The margins are corroded and myrmekitic intergrowths of quartz and oligoclase are common. Microperthite and quartz occur as large poikilitic crystals up to 2 mm. in length. The former has feeble perthitic texture and a soda content of about 20 per cent. Biotite is present in small, partly chloritized crystals, and apatite occurs through the rock in small needle-like crystals up to 0·1 mm. long. The volume percentages of minerals are: Plagioclase 44·6, microperthite 32·3, quartz 21·5, biotite etc. 1·6 per cent.

The rock differs from the granodiorite chiefly in the small content of ferromagnesian minerals and in the more acid plagioclase, and is considered to represent a differentiate of that magma. It is chilled both against the pegmatite and the xenoliths.

(*d*) *The Xenoliths.*

The xenoliths in the pegmatite show great differences in colour and texture and vary in size from about 18 inches across down to small clots and individual xenocrysts (see Text-fig. 1). Except for the smallest they are rounded by absorption and show the effects of marginal penetration by the magma. The mineral constitution is quartz, microperthite, plagioclase, hornblende, pyroxene, and biotite with accessory sphene, apatite, and iron ore, and according to the proportions of these minerals present the xenoliths fall into three groups described below as holomafic, dioritic, and granodioritic. The division, however, is arbitrary, as intermediate types are developed by progressive granitization.

The Holomafic Xenoliths are generally small with diameters of less than 1 centimetre, and they tend to be collected together, particularly towards the edge of the vein (see Text-fig. 1). They consist almost exclusively of hornblende, biotite, and pyroxene, in various proportions, with sphene, apatite, and ilmenite as accessories.

Some of the xenoliths, for example No. 2069, illustrated in Text-fig. 3A, consist of crystals of green hornblende which contain patches of colourless pyroxene. This latter mineral was evidently unstable under the prevailing conditions and was largely converted to the amphibole. The pyroxene has $+ 2\ V = 52°$ and $\gamma \wedge c = 36°$, which indicates that it is one of the clino-enstatite/diopside series, probably with about 80 per cent of the diopside molecule (Winchell, 1933, p. 223). The amphibole is pleochroic with $Z > Y > X$, $Z =$ green-brown, $Y =$ pale greenish-brown, $X =$ straw. $- 2\ V = 66°$ and $\gamma \wedge c = 16°$; properties which indicate a common hornblende almost identical with that in the granodiorite. The conversion of the pyroxene into the amphibole would involve taking up iron and alumina and expelling lime and silica. The iron may have been obtained from ilmenite dust, which is abundant in the rock, and the relict titania may then have combined with the expelled lime and silica to form sphene. The alumina and volatiles required were probably supplied by the magma.

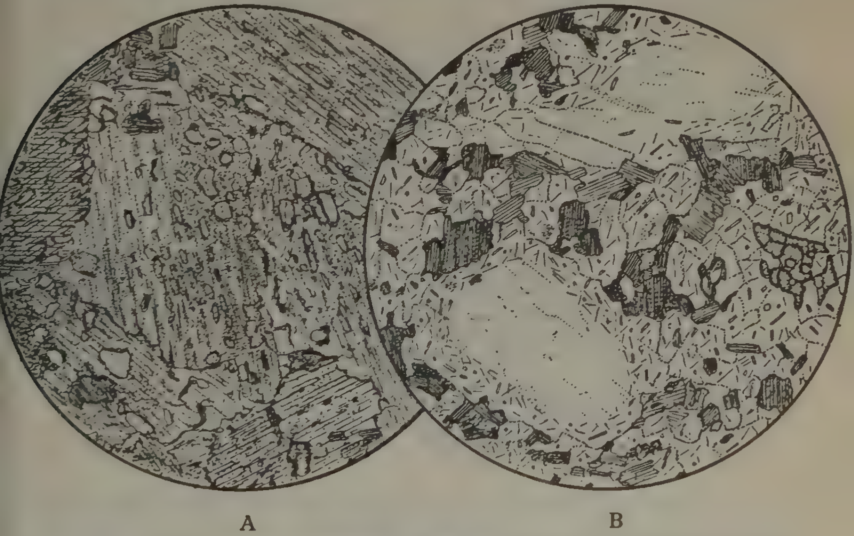
A few of the holomafic xenoliths (e.g. No. 2070) have an almost colourless amphibole in place of the pyroxene. This mineral occurs in small felted crystals and the ilmenite dust is sometimes arranged in such a way as to suggest that it is secondary after pyroxene. The amphibole has faint pleochroism, $Z > Y > X$, $Z =$ pale-green, Y and $X =$ colourless. $- 2\ V = 69°$ and $\gamma \wedge c = 22°$, properties which indicate an amphibole closely allied to tremolite. Its formation from pyroxene would be in the nature of uralitization, involving the addition of volatiles from the magma. Like the pyroxene, this mineral is also largely converted to the same green hornblende. A further conversion which both pyroxene and amphibole suffer is to biotite, but the varying proportions of this mineral in the xenoliths is probably largely due to original differences in composition.

The Dioritic Xenoliths are variable in size. They average about 5 cm. across, but include some of the largest xenoliths in the pegmatite. They are grey or speckled rocks of dioritic appearance, some are equigranular, medium to fine in grain-size, others show either clotting of the dark minerals or the development of leucocratic spots or both features. Small porphyritic felspar crystals are not uncommon. All are linked together, however, by their mineral composition which averages quartz 5, oligoclase/andesine 60, biotite and/or hornblende 30, and sphene, apatite, and ilmenite 5 per cent. Microperthite is present in appreciable quantity only in those types which have suffered penetration by the magma.

A typical fine-grained equigranular xenolith (No. 2073) consists of oligoclase 56·9, biotite 30·7, quartz 6·4, apatite 3·7, sphene

1·9, and ilmenite 0·4 per cent by volume. Oligoclase is in subhedral crystals, which are often turbid centrally or in patches. Its composition is about $Ab_{83}An_{17}$. Zoning is not noticeable. Unlike the oligoclase in the granodiorite the crystals are not corroded, a fact to be expected owing to the absence of microperthite. Some of the larger crystals have patchy extinction and twinning, and seem to consist of several crystals not quite in parallel orientation. Biotite is the same as in the other rocks described, and is associated with sphene and apatite. Quartz is interstitial.

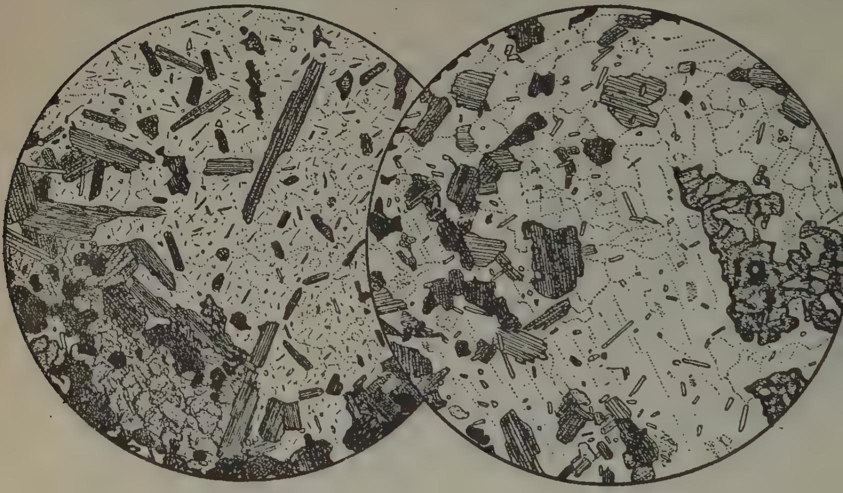
A coarser example of equigranular xenolith (No. 2076), illustrated in Text-fig. 2B, contains oligoclase 66·5, hornblende 15·9, biotite 8·6, quartz 6·1, sphene 0·7, ilmenite 1·7, and apatite 0·8 per cent by volume. The plagioclase crystals have rounded cores of $Ab_{73}An_{27}$ but are sheathed with more acid felspar $Ab_{85}An_{15}$, the junction of the core and the sheath being sharp. The rock was originally richer in lime than the one just described, as is indicated by the more basic plagioclase and the abundant hornblende. This last mineral is the same green species as found in the holomafic xenoliths and the granodiorite. The crystals are ragged and show alteration to biotite. Another xenolith of this type (No. 2077) evidently derived from material less rich in lime has the following mode: oligoclase 57·3, biotite 34, quartz 4·0, apatite 4·7 per cent. Sphene, hornblende, and ilmenite are negligible.


A B

TEXT-FIG. 3.—A: Holomafic xenolith. No. 2069 (× 25). B: Dioritic xenolith. No. 2078 (× 25).

The xenolith (No. 2078), represented in Text-fig. 3B, contains oligoclase 56·8, biotite 28·0, hornblende 1·4, quartz 4·1, apatite 6·7, sphene 2·1, and ilmenite 0·9 per cent. It has the normal hornblende and biotite, but is very rich in apatite, in needles and small crystals, and in sphene. Its most noteworthy feature, however, is the presence of large plagioclase crystals, which have rounded cores of andesine ($Ab_{65}An_{35}$), free from apatite needles, surrounded by sheaths of acid oligoclase ($Ab_{85}An_{15}$), in which apatite needles are abundant.

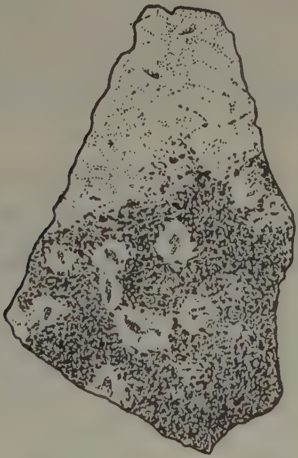
The dioritic xenoliths which show clotting of the dark minerals or the development of leucocratic areas contain microperthite and more quartz due to penetration by the magma. They thus tend more towards a granodioritic composition.



Text-fig. 4.—A : Dioritic xenolith. No. 2075, showing clot of ferromagnesian minerals (× 25). B : Dioritic xenolith. No. 2080, showing leucocratic area with large sphene crystal on right (× 25).

An example in which the dark minerals form clots (No. 2075) is illustrated in Text-fig. 4A. The clots consist of the usual green-brown hornblende and biotite, accompanied by sphene and ilmenite and are in themselves similar to many of the holomafic xenoliths. The rest of the rock consists of scattered corroded crystals of acid oligoclase, biotite, and sphene, all of which are poikilitically enclosed by larger crystals of quartz and microperthite. Apatite needles are abundant throughout. The invading magma which crystallized as quartz and microperthite seems to have made room for itself partly by replacing oligoclase. When this replacement process has been carried to completion, a rock results in which oligoclase is absent and which consists of crystals of microperthite and quartz enclosing biotite and/or hornblende, sphene, and apatite. Such rocks have been found as xenoliths in the granodiorite and have been described by Brammall and Harwood (1932, p. 206) among others. That a quartz-potash felspar magma has corrosive effects on plagioclase was noted in the case of the action of the residual fluid on the oligoclase of the granodiorite.

A xenolith (No. 2080) showing the formation of leucocratic spots is represented in Text-fig. 4B. In the hand specimen (Text-fig. 5) the leucocratic areas resemble boiled barley, being about the same size and having a brown crystal of sphene in the centre resembling the dark marking of the furrow of the grain. Under the microscope, apart from the leucocratic areas, the rock consists of biotite and sphene enclosed in large crystals of acid oligoclase. There is a little interstitial quartz and microperthite and apatite is abundant. The leucocratic spots are devoid of biotite and consist of oligoclase, quartz, microperthite, and sphene. Quartz and microperthite are interstitial and poikilitic with regard to oligoclase. They are much more abundant than in the rest of the rock. Sphene is normally present in the form of one large crystal near the centre of the spot, though occasionally there may be two or three crystals, and sometimes a crystal of hornblende. The sphene and the hornblende when present enclose small oligoclase crystals.



Text-fig. 5.—Polished surface of dioritic xenolith. No. 2081, showing leucocratic spots (× 2).

Finally, some of the dioritic xenoliths (e.g. No. 2084) have small porphyritic crystals of plagioclase and resemble porphyrites. The phenocrysts, which are up to 2 mm. in length, have a composition of about $Ab_{70}An_{30}$ and are margined with the usual acid oligoclase ($Ab_{85}An_{15}$). There are a few hornblende crystals up to 1 mm. long. The base of the rock is fine-grained and equigranular and consists of quartz, microperthite, acid oligoclase, biotite, and a little hornblende and sphene with abundant apatite.

The differences between the dioritic xenoliths seems to be due largely to the extent of magmatic penetration and only to a small extent to original differences in composition.

The Granodioritic Xenoliths are generally of relatively large size, up to 6 inches across, and are all well-rounded. In the hand and under the microscope many of them are indistinguishable from the granodiorite of the quarry, the rest differ only in respect of the mineral proportions. It is unnecessary to describe them in detail. The modes of two examples are given in the table on p. 181. There is no doubt that these xenoliths are derived from the granodiorite.

III. INTERACTION OF THE XENOLITHS AND THE PEGMATITE.

The assimilation of basic xenoliths by acid magma has been described by many workers and in particular Nockolds, whose views, as summarized in a recent paper (Nockolds, 1933), find confirmation in the present study.

Nockolds points out that there are two processes involved in assimilation. Firstly the conversion of the minerals of the xenolith into phases which are in equilibrium with the magma by the process of " reciprocal reaction ", and secondly the dispersal of the material of the xenolith into the magma by the process of " mechanical disintegration ".

The first process can be observed only to a partial extent in the xenoliths here described, as with the exception of the granodioritic types all have already undergone considerable alteration from unknown original rocks. Evidence for the process, however, is found in the formation in the xenoliths, by reciprocal reaction with the pegmatite, of minerals identical with those which were in equilibrium with the granodiorite at the stage when the residual liquid in that rock was of pegmatitic composition.

In the holomafic xenoliths the ferromagnesian material, whether it was pyroxene or amphibole, was being converted to the brown-green hornblende or the brown biotite characteristic of the granodiorite (see p. 172). These changes involve the addition of alumina, alkalis, and volatiles, particularly water, and P_2O_5 seems to have been abundant and combined with the excess lime to form apatite.

In the dioritic xenoliths the adjustment of the mafic minerals was complete, but the plagioclase was being converted to acid oligoclase (Ab$_{65}$An$_{15}$). This is the final type of plagioclase in the granodiorite. In many of the xenoliths this mineral takes the form of poikiloblastic crystals, in others it forms reaction margins to earlier plagioclase. The felspar conversion involves particularly the introduction of soda, and that volatiles were again important in the process is indicated by the abundant apatite formed from the lime thrown out in the reaction (see Text-fig. 3B).

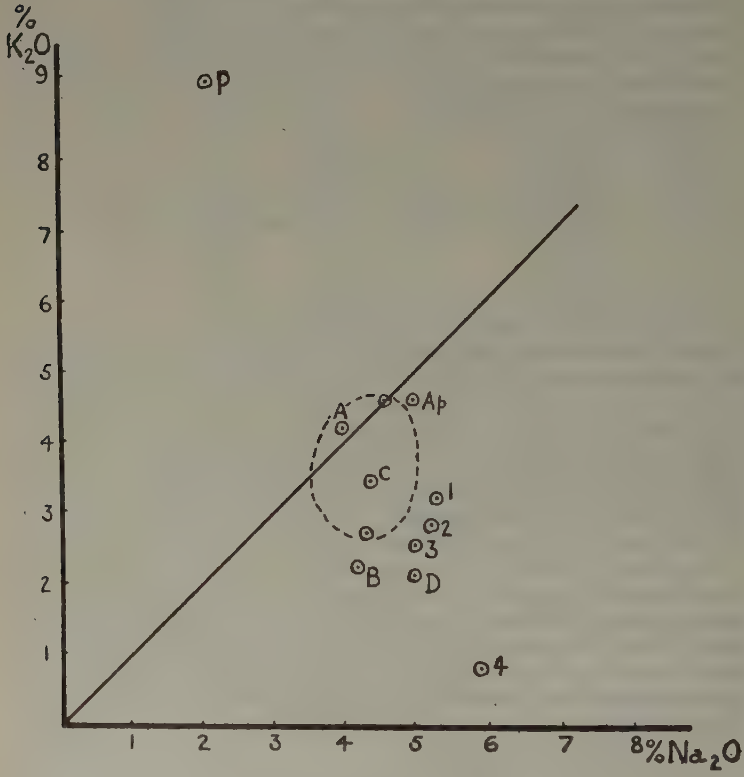
In the case of the granodioritic xenoliths the original composition is known and some idea can be got of the material which the magma was capable of extracting from its xenoliths. In the table below are given the modes of two representative granodioritic xenoliths, Nos. 2090 and 2091, under A and B, and the normal granodiorite, C. Except for a small deficiency in oligoclase the xenolith, A, falls within the variability of the normal granodiorite. It has not been altered appreciably. The xenolith, B, is poor in microperthite and rich in quartz, and it is suggested that this is due to solution of microperthite leading to a spongy rock in whose mesh, at a later stage, quartz crystallized. This is what would be expected in view of the fact that potash-felspar was the last mineral to crystallize in the rocks. Quartz does not seem to have been dissolved either in these xenoliths or in the dioritic varieties.

	A.	*B.*	*C.*	*D.*
Quartz . .	24·9	30·7	22·4	26·1
Microperthite .	24·6	11·5	20·7	11·8
Oligoclase . .	39·4	43·8	46·9	55·0
Hornblende .	0·2	4·4	1·6	0·6
Biotite . .	9·5	7·5	6·3	5·2
Sphene . .	0·9	1·0	1·0	0·4
Ilmenite	0·5	0·5	0·6	0·7
Apatite .		0·6	0·5	0·2

It seems probable that at an early stage potash-felspar was removed also from the dioritic xenoliths. It must certainly have been removed if their original composition was as suggested below (see p. 182). The mineral changes in the dioritic xenoliths would then be in accord with Bowen's theory of reactive solution (1928, p. 221), potash-felspar being the late phase which the magma could dissolve, and acid oligoclase the phase with which it was in equilibrium and which was precipitated.

The composition of the granodiorite wall of the pegmatite vein is suggestive in this connection. It is given in the above table, D, and compared with the normal granodiorite, it shows poverty in microperthite and richness in oligoclase.

The soda/potash ratio of some of the rocks is shown in Text-fig. 6. For the purpose of this diagram the weight percentages of the alkalis have been calculated on the basis of 11·8 per cent soda in the albite molecule, 16·9 per cent potash in the orthoclase molecule, and 8·5 per cent potash in biotite. Soda in hornblende has been neglected. The diagram shows the field of the granodiorite with the average granodiorite marked C, and the potassic pegmatite differentiate marked P. The aplite differentiate (Ap) differs from the parent chiefly in the loss of ferro-magnesian minerals. The granodioritic xenolith (B of table, p. 181) shows loss of potash by solution of microperthite while the granodioritic xenolith (A of table, p. 181) is unaffected. The marginal granodiorite (D of table, p. 181) also shows loss of potash, but here there is a rise in the soda content owing to the increase in oligoclase. The dioritic xenoliths 1–4 (Nos. 2077, p. 177; 2073, p. 176; 2078, p. 178; 2076, p. 177), which have not been penetrated by the magma, are soda rich, in particular (4), which is the type rich in lime. A preferential enrichment of xenoliths in soda has been noted by many workers, for instance Brammall (1932, pp. 199 and 205; 1933, p. 99), and Nockolds (1933, p. 571).



TEXT-FIG. 6.

The process of mechanical disintegration is exhibited by nearly all the xenoliths. It takes place apart from the process of reciprocal reaction and also as a consequence of it. The growth of oligoclase porphyroblasts as a result of the process leads to clotting of the ferromagnesian minerals and tends to disrupt the xenoliths. As noted above, the deposition of oligoclase was probably accompanied by the solution of potash-felspar. This would lead at a certain stage to a spongy rock which would disintegrate easily. Disruption is also caused by the growth of minerals of the pegmatite—quartz and microperthite—within the xenoliths and by marginal attack by the magma.

The growth of leucocratic spots (see No. 2080, p. 179) is connected with magmatic penetration. As these are evenly distributed through the xenolith it is suggested that the magma did not wedge its way in but that material to form the quartz and microperthite-rich spots diffused through the xenoliths to certain points where pools of magma were formed. Possibly some of the material to form the quartz and microperthite of the spots may have originated in the xenolith itself, in which case they are analogous to the spots in spotted slate (see Harker, 1932, p. 15). Biotite was evidently thrown aside when the spots crystallized, but it is difficult to account for the big sphene crystals. Possibly titania diffused to the area and there combined with lime and silica which would be available.

Where the quartz-potash felspar magma came into contact with oligoclase this mineral ceased to be stable and was replaced (see No. 2075, p. 178), the albite molecule probably being accommodated in microperthite and the lime joining with volatile P_2O_5 to yield apatite. This process is comparable to the corrosion of oligoclase crystals by residual liquid in the granodiorite. Late biotitization of hornblende and pyroxene also occurred as a result of penetration of potash-rich magma.

As the xenoliths were disintegrated, clots and individual crystals of ferromagnesian minerals, sphene, apatite, and plagioclase were strewn through the pegmatite magma. That these minerals are not more abundant in the crystallized pegmatite and that they are not concentrated round the xenoliths is attributed to the streaming action of the magma.

The assimilating power of the pegmatite must be due to its high content of volatiles and not to its temperature, which may have been relatively low. Nockolds (1933, p. 569) has stressed the importance of volatiles in assimilation and there is ample evidence in the present case that they played an important role. In this connection the pegmatite may be contrasted with the volatile-poor aplite, which is chilled both against the pegmatite and the xenoliths.

It is interesting to note that Deer (1935, p. 73), writing of the rocks of the Cairnsmore of Carsphairn complex, attributes the hybridization of basic rocks to the "partial magma" of a tonalite. The "partial magma" was composed of potash-felspar, quartz, and volatiles which is the composition of the pegmatite here described.

IV. THE ORIGIN OF THE XENOLITHIC PEGMATITE.

Although there is no direct evidence, it is probable that the pegmatite rose from a lower level in the granodiorite. Did it bring up the xenoliths with it?

It is difficult to imagine a fluid magma carrying up xenoliths, many of which are large and have a relatively high specific gravity, but it is just possible that intrusion was sufficiently rapid for the magma full of xenoliths to have been squirted into the fissure. The mode of origin of such a magma, however, presents a difficulty. The pegmatite is no doubt a squeeze out of residual liquid material from crystallizing granodiorite. It would therefore originate in the pores of the consolidating rock, and it is difficult to understand how under these conditions it could have caught up the xenoliths.

The following is the mode of origin favoured. The fissure, which was filled with pegmatite, passed not only through the granodiorite but also through the country-rocks at a level now removed by denudation. This is quite possible as the pegmatite is not more than 200 yards from the outwardly dipping margin of the granodiorite intrusion. The xenoliths originated in detached fragments and blocks of the fissure-wall which sank down through the pegmatite magma, the granodioritic types being derived from the granodiorite and the dioritic types from the country-rocks. The country-rocks consist of hornfelses formed from calcareous shale and greywacke such as would give the types of xenoliths found, and many xenoliths of undoubted hornfels origin, which occur in the plutonic rocks of the Criffell-Dalbeattie complex, can be matched with those here described. The country-rocks are cut by porphyrite dykes older than the granodiorite and some of the xenoliths, particularly those with porphyritic plagioclase and hornblende (see No. 2084, p. 179) may have originated in these rocks. The holomafic xenoliths are in part relics of the disintegration of other xenoliths, especially clotted types, but as they are relatively small some of them may have been brought up by the pegmatite. The presence of pyroxene also suggests an origin distinct from that of the other xenoliths.

V. SUMMARY AND CONCLUSION

A pegmatite cutting granodiorite contains abundant xenoliths which are in various stages of assimilation. Assimilation involved the conversion by the process of "reciprocal reaction" of the minerals of the xenoliths into species which were in equilibrium under the prevailing magmatic conditions, and the subsequent "mechanical disintegration" of the xenoliths with the strewing of their minerals in the pegmatite. Solution of xenolithic material was not important, probably only affecting potash-felspar. The fact that the active magma was a pegmatite suggests that high temperatures were not available, and its assimilating power must be attributed to its large volatile content. The xenoliths were probably derived from the walls of the pegmatite vein both in the granodiorite and in the country-rocks.

In conclusion, I have to thank Dr. S. R. Nockolds for kindly reading through the manuscript and for helpful suggestions and criticism, and Mr. P. A. Johnson for making the necessary rock-sections. The material which is the subject of this paper is housed in the geological collection at University College, London.

References.

Alling, H. L. 1921. "The Mineralogy of the Feldspars," *Journ. Geol.*, xxix, 193–294.
Bowen, N. L. 1928. *The Evolution of Igneous Rocks*, Princeton.
Brammall, A., and Harwood, H. F. 1932. "The Dartmoor Granites: Their Genetic Relationships," *Quart. Journ. Geol. Soc.*, lxxxviii, 171–238.
—— 1933. "Syntexis and Differentiation," Geol. Mag., LXX, 97–107.
Clarke, F. W. 1924. *The Data of Geochemistry*, Washington.
Deer, W. A. 1935. "The Cairnsmore of Carsphairn Igneous Complex," *Quart. Journ. Geol. Soc.*, xci, 47–76.
Harker, A. 1932. *Metamorphism*, London.
Nockolds, S. R. 1932. "The Contaminated Granite of Bibette Head, Alderney," Geol. Mag., LXIX, 433–452.
—— 1933. "Some Theoretical Aspects of Contamination in Acid Magmas," *Journ. Geol.*, xli, 561–589.
Teall, J. J. H. 1896. In "Explanation of Sheet 5 (Kirkcudbrightshire)," *Mem. Geol. Surv. Scot.*

Earth-Movements, Ice Ages, and Faunas.

By A. Tindell Hopwood, Department of Geology, British Museum (Natural History).

NEARLY thirty years ago Penck and Brückner published *Die Alpen im Eiszeitalter*, which has moulded the views of European glacialists over since. It is the basic authority for the theory that there were four glaciations—the familiar Günz, Mindel, Riss, and Würm—separated by three warm interglacial periods. This theory has been further elaborated to such an extent that Zeuner (1935) lists some eight or nine glacial phases with a corresponding number of intervening warm phases.

In England, on the other hand, it is not yet possible to make any close correlation with the Alps and Central Europe. There are two main reasons for this: Firstly, in the northern half of the country, the destruction of earlier deposits by glaciers which pushed inland from the coasts to heights of between 1,200 and 1,300 feet, with the subsequent alteration of the topography by marginal retreat phenomena; and, in the South, the effects of outwash. Secondly, most of the Pleistocene fossils in the various museums have not been collected with that precision which is necessary for faunistic researches on modern lines. Nevertheless, the efforts of numerous workers have confirmed the theory that in England, too, there was more than one glaciation.

In face of so much evidence from careful, detailed, stratigraphical work, supported, as Zeuner shows it to be, by various astronomical and physical theories, it is hardly surprising that Palaeontology should tend to be regarded with suspicion when it seems to tell against the prevailing dogma. The imperfection of the fossil record is notorious!

At the same time it is disturbing when Hinton (1926) says that "the 'glaciation' of Britain was one of the latest events of the Pleistocene period; and if that be true even the comparatively sober judgment of Sir A. Geikie of the Geological Survey must be rejected, while the bolder flights of Penck may well be left alone as details irrelevant to the present discussion". That is the considered verdict of our highest authority on Pleistocene mammals, and it is in direct contradiction to accepted geological teaching. Apparently there can be no compromise.

Lately (1933) that eminent authority, Professor H. G. Stehlin, of Basel, has expressed himself in much the same way. He points out that although the continental Pleistocene deposits give evidence of two earlier cool periods, which he correlates with the Mindel and Riss, they did not affect the fauna to any very serious extent, and that the period of cold which decimates the mammals is associated with the Würm. He further suggests that the difference between the earlier glaciations and the Würm may in some way be connected with a process of mountain building in the Pleistocene. In France, also, as well as in Germany, Hungary, and elsewhere, it has been shown that the real "cold fauna" comes in during the Upper Pleistocene.

My own studies on the collections of African Pleistocene mammals which have reached the British Museum through the generosity of various collectors, notably of Dr. Leakey, have revealed the fact that even in Kenya and Tanganyika the big faunal break comes late in the Pleistocene, although there "warm" and "cold" faunas are not in question. In India, too, precisely the same thing happens. It seems evident, therefore, that some major geological event must have so affected the general conditions over a far wider area than Europe that the greater part of the faunas became extinct, leaving an impoverished remnant behind. The problem resolves itself into the nature of this geological event, and into an endeavour to be more precise as to the period when it occurred.

In Africa the solution is relatively simple. There the tectonics are on so vast a scale that it is not possible to overlook them, and the Rift Valley region gives all the data necessary.

At Olduvai the sequence of events is :—

(i) A lava flow, probably connected with the old volcano Lemagrut.

(ii) Deposition of the four beds of the main Olduvai series during a relatively moist climatic period.

(iii) Earth movements, step-faulting, and erosion.

(iv) Deposition of the dry Bed V unconformably on Beds I to IV.

At Olduvai itself nothing is known of whatever may underlie the basal lava flow, hence the importance of Dr. Leakey's discovery of fossiliferous beds a few miles farther south, capped by lava flows coming from the somma of Lemagrut. The fauna from this new locality agrees with that from Olduvai. Both contain *Dinotherium*, *Sivatherium*, *Giraffa*, "*Equus*," *Hipparion*, the white rhinoceros, and giant pigs of the *Metridiochoerus* group, but there seems to be one difference between them. At Olduvai remains of hippopotamus, crocodile, and fish are common ; they do not occur in the newly found fauna as far as I know. This means that the beds in question are the sub-aerial equivalent of Bed I at Olduvai, and suggests that the sub-lava deposits at Olduvai also may be of Middle Pleistocene age.

Once the unconformity between the fourth and fifth beds at Olduvai is crossed there is a marked change. The old assemblage of species has given way to the modern African fauna. Fossils are regrettably rare in Bed V, but additional evidence is at hand from the Naivasha area of Kenya. Near Naivasha the older beds are almost devoid of fossils, but they contain *Hipparion* and the large zebra found at Olduvai. Unconformable on these beds is a fossiliferous series containing the modern African fauna. It seems reasonable to assume, therefore, that the earth-movements which affect the older beds of Olduvai and in the Naivasha area were in some manner connected with the extinction of the older fauna.

In India a similar connection between the older fauna and earth-movements has been observed. The fauna is contained in deposits laid down by the westward-flowing Indo-Brahm. At the end of the period of deposition earth-movements took place which gave rise to a reversal of drainage and the substitution of the eastward-flowing Ganges for the Indo-Brahm. Here again the earth-movements were accompanied by widespread extinction.

Both in Africa and in India these very different types of crustal adjustment—rifting in Africa, folding in India—affect beds of Lower and Middle Pleistocene age, using those terms in the sense adopted in a recent paper (Hopwood, 1935). They are, therefore, later than the Middle Pleistocene.

The mechanism involved is perhaps not so clear as one could wish. To me and, as one might infer from his writings (cf. Pilgrim, 1919), to Pilgrim also, it appears as the last and greatest northward drive of the African block, which caused the final uplift of the whole alpine chain from the Mediterranean through Asia Minor to the Far East, breaking the hammer and cracking the anvil in the process. Others, may be, will see in those same movements mere isostatic adjustments of no very great moment (but see also Penck, 1925).

Here is at least a partial explanation of the discrepancy between the geological and palaeontological views concerning the Pleistocene. Stehlin points out that the Würm glaciation is peculiar on account of the intense dry cold, and that it was this peculiarity which caused the faunal changes. No doubt the fluctuations in the solar radiation postulated by various authorities may have caused this ice age and those which preceded it, but the distinctive cold and dryness are to be attributed to the newly erected mountain barriers stretching right across Eurasia.

Both in the four-fold curve of the Glacialist and in the single curve of the Palaeontologist only one portion is really significant, namely that which represents the Würm. Any fluctuation before that is of small significance compared with a peak which denotes a change of climate sufficient to annihilate faunas, to turn previously fertile areas into deserts, and to demonstrate final adjustment of crustal movements begun in early Tertiary times.

LITERATURE.

HINTON, M. A. C., 1926. "The Pleistocene Mammalia of the British Isles and their Bearing upon the Date of the Glacial Period," *Proc. Yorks. Geol. Soc.*, N.S., xx, 325–348.

HOPWOOD, A. T., 1935. "Fossil Elephants and Man," *Proc. Geol. Assoc.*, xlvi, 46–60.

PENCK, A., 1925. "Glazialgeologische Beobachtungen i. d. bayerischen Hochalpen," *Sitzber. Preuss. Akad. Wiss.*, Jahrg., 1925, 301–329.

—— "Alte Breccien u. junge Krustenbewegungen i. d. bayerischen Hochalpen," ibid., 330–348.

—— "Die Eiszeit i. d. bayerischen Hochalpen," ibid., 349–371.

PILGRIM, G. E., 1919. "Suggestions concerning the History of the Drainage of Northern India, etc.," *Journ. Asiatic. Soc. Bengal*, N.S., xv, 81–99.

STEHLIN, H. G., 1933, *in* DUBOIS, A., and STEHLIN, H. G. "La Grotte de Cotencher, Station Moustérienne," *Mém. Soc. paléont. Suisse*, lii–liii.

ZEUNER, F., 1935. "The Pleistocene Chronology of Central Europe," GEOL. MAG., LXXII, 350–376.

REVIEWS.

AN INTRODUCTION TO PHYSICAL GEOLOGY, WITH SPECIAL REFERENCE TO NORTH AMERICA.

3rd Ed. By WILLIAM J. MILLER. pp. x + 465, with frontispiece and 397 figures in text. London: Chapman and Hall, Ltd., 1935. Price 15*s*.

THE author of this book is Professor of Geology in the University of California, Los Angeles, and his book is intended primarily for American students. It appeared first in 1924, and since both the previous editions were reprinted twice it evidently meets a wide demand. To illustrate the work of geological agents he naturally chooses American examples and he seldom finds it necessary to go outside the American continent.

Like several other American textbooks of the same and allied subjects, the book is profusely illustrated. The figures, with their explanatory titles, occupy about half as much space as the text itself, and nearly three-quarters of the pages have one or more illustrations upon them. Most of them are half-tone reproductions of photographs, in which the lights are somewhat degraded, and it is a pleasant change to come across an occasional line-drawing. There are, indeed, sufficient of these, but they form only a small proportion of the whole number.

The book is a sound and well-balanced textbook of its subject and the English student will find its numerous American examples useful and interesting. There is a good index but no list of illustrations.

P. L.

SEDIMENTPETROGRAPHISCHE UNTERSUCHUNGEN AN MOLASSESANDSTEINEN.

By A. VON MOOS. Schweiz. Min. Petr. Mitt., Band XV. 1935.

THE term "Molasse", first introduced by de Saussure in 1796, originally applied to the soft Middle Tertiary sandstones of Western Switzerland, and was afterwards extended to designate all the deposits of similar date and origin in that region. It is perhaps to be regretted that it has since been used by various writers as descriptive of a facies, of whatever age; namely sediments which are a direct result of denudation following an orogenic uplift, whereby some confusion has been introduced into the literature. In the publication now under review the investigation is confined to the sandy members of the 20,000 feet or so of mixed sediments which border the northern flank of the Alpine chain and are a direct result of the Alpine orogeny. The materials composing such a deposit must obviously be of local origin, and in this case must reflect the mineral composition of the rocks of the Alpine chain. It is therefore not surprising that the author finds a considerable similarity throughout the region; in fact, the whole area is probably best regarded as constituting a single mineral province, with its own characteristics, and little or no indication of important changes of conditions during the period of deposition: this is quite consistent with the history of the region as derived from other considerations.

The method of work adopted is based primarily on examination of the mineral constituents that sink in bromoform, the "heavy minerals" in the usual sense, while attention is also paid to grain-size. With regard to the difficult question of how the results are to be expressed, Dr. v. Moos has devised a simple method which has much to commend it from the practical point of view. He establishes three categories based on frequency of minerals in the concentrates: Hauptgemengteile (major constituents), those amounting to over 10 per cent; Nebengemengteile (minor constituents), from 10 to 2 per cent; and accessories, less than 2 per cent. This seems to the present writer to be an eminently practical solution of a difficult problem, and one which could be applied approximately without the infinitely laborious process of actual counting of grains. In most heavy mineral concentrates it is obvious that some species are dominant; some important though less abundant; and others rare but interesting and perhaps characteristic. But little importance can be attached to actual quantitative determinations based on weighing, owing to the unfortunate tendency of the minute grains of heavy minerals to stick to the apparatus during separation.

The memoir under review must be regarded as an excellent practical illustration of the application of common sense methods to a difficult branch of sedimentary petrology.

R. H. R.

CORUNDUM IN THE UNION OF SOUTH AFRICA. By W. KUPFERBURGER. pp. 81. Bull. 6, Geological Series, Department of Mines, Pretoria, 1935.

THE curious corundum-bearing rocks of the Transvaal are well known to most petrologists, but the literature is rather scattered, and it is convenient to have a connected account brought up to date in a single bulletin. Three chief types are recognized: plumasite, plagioclase-corundum rocks, with dark mica; marundite, rocks composed of margarite and corundum with a little felspar; and corundum-gneisses. Many intermediate types exist. It is now generally agreed that corundum is produced in them by desilication of pegmatitic magma on intrusion into very basic rocks, especially serpentines.

The bulletin gives an account of all known deposits, including some new ones in the Zoutpansberg district, and much useful information as to mining, dressing methods, and statistics.

THE GEOLOGY OF THE KLERKSDORP-VENTERSDORP AREA. By L. T. NEL. pp. 159, with 12 plates and 5 text-figs. Union of South Africa Geological Survey, Pretoria, 1935.

IT has long been known that the Witwatersrand system, which contains the most important gold-bearing horizons of the Rand, extends far to the south-west, as indicated in Dr. Hatch's well-known map of 1903 and indeed some production began in the Klerksdorp district as early as 1889. Lately, owing to the rise in the price of gold, much exploration has been done in this and adjoining areas, while many perhaps exaggerated reports have appeared in the Press as to possible developments on the large scale. Hence the appearance of these maps and memoirs is very welcome. The detailed mapping was begun by Dr. Rogers in 1923, but pressure of other work obliged him to hand it over to Dr. Nel, who began field work in 1931. The explanation covers two sheets of the geological map, which owing to the great interest of the area have been published on the scale of 1 : 60,000, thus making them uniform with those of the Witwatersrand and Heidelberg.

Some notable features of the geology are the very complicated structure of the area, which makes correlation with the Rand difficult for isolated outcrops ; the much more strongly marked unconformity between the Witwatersrand and Ventersdorp systems ; and the presence of two bands of tillite in the Lower Witwatersrand, probably the same as those first found by Dr. Rogers in the Heidelberg district and since identified on the West Rand : these are useful markers.

The reefs already worked near Klerksdorp appear to be the equivalents of the Government Reef series of the Rand and therefore well below the Main-Bird series, the most important producers : this seems to be represented near Klerksdorp by the Commonage and Ada May reefs, according to the section given on p. 60 of the explanation.

The general impression to be gained from Dr. Nel's description is that most of the reefs are both thin and lenticular, not extending very far laterally, although in some of the old mines fairly rich pay-streaks were found here and there. But it would also appear that much secrecy is being maintained as to the results of recent exploratory work, and it is advisable to avoid the expression of any opinion as to future possibilities.

CORRESPONDENCE.

ON BABABUDANITE.

SIR,—In his article on bababudanite (GEOLOGICAL MAGAZINE, LXXIII, 1936, 39–45), Professor C. S. Pichamuthu states that this mineral has so far been considered in Mysore to be an original mineral of basic igneous rocks, which is not quite a correct representation of facts.

It was only in 1907 when the mineral bababudanite was first discovered that it was regarded as an original constituent of the amphibolites and this view was expressed in 1908.[1] But later on, in 1920, Mr. B. Jayaram, then Director of the Survey, on a re-examination of this area, found the mineral to be of a secondary metamorphic character—a fact which will be quite evident by a reference to his report.[2] Apart from this mineral, some riebeckites, cummingtonites, and other ferruginous amphiboles from several other parts of the Mysore State have also been regarded as of secondary origin.[3]

Whatever might be the view held regarding the origin of the ferruginous quartzites, it is clear that bababudanite and other allied ferruginous amphiboles have been long regarded in Mysore as secondary minerals of metamorphic origin.

B. RAMA RAO,
Director,
Mysore Geological Department.

13th February, 1936.

---

[1] *Rec. Mysore Geological Dept.*, ix, 1908, 86.

[2] Ibid., xx, 1923, 40–2.

[3] Ibid., xxi, 1924, 52, 60, 170, 171; xxiii, 1926, 63, 100; also *Bull. Mys. Geol. Dept.*, No. 15, 1934.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIII.

No. V.—MAY, 1936.

ORIGINAL ARTICLES.

Heavy Accessories of certain pre-Cambrian Intrusives of the Canadian Shield.

By E. L. Bruce and Walter Jewitt, Queen's University, Kingston, Ontario.

Introduction.

INTENSIVE study of the heavy accessory minerals and comparison of the suites of them occurring in igneous rocks has recently received much attention. In 1915 Rastall and Wilcockson examined the heavy accessories from granites of the English Lake District in connection with a study of the mineral constitution of certain sandstones. They found a wide variation in the accessory minerals of the granites, but a distinct similarity in those from all phases of the igneous mass.[1]

An attempt to use the heavy accessory minerals as a means of correlation of igneous rocks was made by A. W. Groves in a study of the granites of the Channel Islands. From the study of the suites obtained he concluded that there was definite confirmation of the existence of a " Newer " and an " Older " granite on the island of Jersey and later he extended the correlations to other of the Channel Islands.[2]

In this work Groves made use of an " index " figure which is the weight per cent of the heavy minerals in a sample. He included as heavy minerals all those of a specific gravity greater than that of bromoform.

---

[1] R. H. Rastall and W. H. Wilcockson, " The Accessory Minerals of the Granitic Rocks of the English Lake District," *Quart. Journ. Geol. Soc.*, lxxi, 1915, 592, et seq.

[2] A. W. Groves, " The Heavy Accessory Minerals of the Plutonic Rocks of the Channel Islands. 1 : Jersey," Geol. Mag., LXIV, 1927, 291, et seq. " 2 : Guernsey, Sark, and Alderney," ibid., 457–473.

P. K. Ghosh studied the heavy minerals of the Falmouth granite and W. Mackie those of Scottish granites.[1]

Groves examined granites in Brittany and Normandy and on the basis of the heavy accessories they contain correlated them with the Jersey granites.[2]

The chief minerals used by Groves for correlation purposes are those that he calls primary stable minerals—zircon, apatite, rutile, sphene, muscovite, biotite, hornblende, iron ores, and, next in importance, the pneumatolytic minerals. The colours, dimensions, habits, nature of inclusions, and other peculiarities are considered to be of much importance. Groves argued that the primary stable minerals :—

> " Generally crystallize from the magma at an early stage of cooling and thus in their colour, inclusions, habits, and peculiarities give valuable characteristics dependent on the original composition and early cooling history of the magma." [3]

A. K. Wells criticized the methods of Groves and argued that of the eight minerals listed as primary stable minerals only three—zircon, apatite, and monazite—are necessarily primary. All the others may be secondary or pneumatolytic.[4]

Reed and Gilluly attempted to apply the method to certain granites of Eastern Oregon. They found that the " index " figure, as determined from crushed material, did not agree with the figure as calculated from chemical analyses, but they found certain striking similarities in the accessory minerals of biotite-quartz diorites collected over a distance of 30 miles. They found less similarity in those of more basic rocks.[5]

J. D. Turner studied the heavy accessories of certain diabases from northern Ontario and northern Quebec. His results were presented in a paper to the Royal Society of Canada (1933), but only an abstract was published. His material consisted of two specimens of Nipissing diabase from the sill at Cobalt and four specimens from dykes of diabase from the Rouyn district in Northern Quebec. These latter came from the large dyke at the Aldermac mine and from the Horne dyke, the Powell dyke, and an east–west dyke at the Noranda mine. It seemed that if the method proved applicable the question as to the age of the Noranda dykes might be settled. Lithologically all of these diabases are very similar. The Cobalt diabase is certainly younger than the Cobalt Series, the Noranda diabase (later gabbro) on rather negative evidence, has been classed as pre-Cobalt in age.[1]

---

[1] P. K. Ghosh, " The Mineral Assemblages of the Falmouth Granite," *Proc. Geol. Assoc., London*, xxxix, 3, 1928, 337. W. Mackie, " The Heavier Accessory Minerals in the Granites of Scotland," *Trans. Edin. Geol. Soc.*, xii, 1, 1928, 31.

[2] A. W. Groves, " The Heavy Mineral Suites and Correlation of the Granites of Northern Brittany, the Channel Islands, and the Cotentin," GEOL. MAG., LXVII, 1930, 218–240.

[3] A W. Groves, op. cit., p. 234.

[4] A. K. Wells, " The Heavy Mineral Correlation of Intrusive Rocks," GEOL. MAG., LXVIII, 1931, 255.

[5] J. C. Reed and James Gilluly, " Heavy Mineral Assemblages of some of the Plutonic Rocks of Eastern Oregon," *American Mineralogist*, xvii, 1932, 207.

Turner found, in the Cobalt diabase, colourless crystals of apatite, most of which have sharp outlines. They appear to have the prism terminated by basal parting planes. None of them contains inclusions.

Most of the diabases from Rouyn contain apatite crystals with simple combinations of the prism and pyramids. In only one, that from the east–west dyke, are the crystals terminated by basal partings. All of these apatites contain rod-like inclusions of a greenish mineral arranged parallel to the vertical crystallographic axes.

Magnetite was not found by Turner in the specimens from Cobalt. Those from Rouyn contain 4·5 to 9 per cent of that mineral. Apparently the failure to find it in the heavy concentrates from Cobalt does not prove its absence from the diabase in that area, as it is mentioned in all descriptions of diabase from the Timiskaming region.

M. F. and C. M. Boos concluded that the " heavy accessory minerals from certain granites of the Front range in Colorado are widespread and distinctive. Allanite and coloured, zonal, clouded, and corroded zircons, together with etched apatite crystals characterize the granites."[2]

W. F. Jenks in a study of the syenite of Pleasant Mountain, Maine, concluded that the heavy accessory minerals are practically useless as indexes of rock types, since the proportions of them " vary almost as much within a rock type as within the stock as a whole, but the crystal habit and colour are, in addition, practically invariant ".[3]

In a discussion of this paper Marsden disagreed with the conclusions drawn. He argued that the syenite studied by Jenks is a single igneous mass and that far from disproving the value of the heavy accessories as criteria for rock correlation, the constancy of the true accessory minerals in the syenite is exactly what would be expected.[4]

SCOPE OF PRESENT INVESTIGATIONS

Some of the work included in the present contribution was done by N. D. Runnalls in 1932–3, and is contained in a report to the

---

[1] H. C. Cooke, W. F. James, J. B. Mawdsley, *Mem.* 166, *Geol. Surv. of Canada*, pp. 24, 141–4.

[2] M. F. and C. M. Boos, " Granites of the Front Range," *Bull. Geol. Soc. America*, xlv, 1934, 331.

[3] W. F. Jenks, " Heavy Minerals in the Syenites of Pleasant Mountain, Maine," *Am. Mineral*, xix, 1934, 476–9.

[4] Ralph W. Marsden, ibid., xx, 1930, 132–8.

National Research Council of Canada, May, 1933. Runnalls's work was an examination of the heavy accessories in a small granite batholith invading Timiskaming sediments at Red Lake (Text-fig. 1) district of Patricia, Ontario. The other granites investigated were collected by W. Jewitt in the Swayze-Woman River area of North-Western Ontario, from granite masses which intrude both Keewatin and Timiskaming rocks (Text-fig. 1). For purposes of comparison heavy accessory minerals from the granite intruding Grenville sediments near Kingston were also examined (Text-fig. 1).

TYPES OF HEAVY ACCESSORIES FOUND.

Zircon crystals of two different types were found in all samples. The more abundant type is tawny in colour, usually simple in form, with well-developed prism and pyramid faces. In most cases there are steep pyramidal faces, possibly 331, terminated by what are probably unit pyramids. Many of these crystals show beautiful zoning, which appears to be due to minute opaque inclusions regularly arranged. There are also zircons in which the inclusions have no regular arrangement. The following types of inclusions were noted :—

1. Reddish brown clots with or without a darker core.
2. Dust-like material in cloudy aggregates.
3. Cavities.
4. Definite tiny crystals.

It seems possible that the opaque material may be magnetite, hematite, rutile, or ilmenite, since it must be some substance that crystallizes early in the cooling history of the rock. The cavities are apparently entirely filled either with gas or liquid, since no movement can be see in them. Tiny included crystals are numerous, but they are so small that the only indication of their identity is the crystal form. On this basis zircon, apatite, and biotite are believed to be present ; all of them are arranged in a haphazard way within the host zircon.

The other type of zircon is limpid ; the crystals are smaller than those of the tawny variety, and are stouter in habit, but the same faces seem to be present. In some of them there are cavities which in one crystal found occupies a large part of it (Text-fig. 5, No. 18).

Apatite is the most abundant accessory in all samples of granite examined. Three varieties of it are recognizable : (*a*) Water clear ; (*b*) pale yellowish green ; and (*c*) bluish green. The water clear crystals are usually most abundant, but generally some crystals of all three types are to be found in every granite. Some of the crystals are short and stumpy, others are acicular in habit. Both types are terminated by pyramidal faces and the basal pinacoid. Many of the crystals are rounded and corroded. Fragments are more common than perfect crystals in the concentrates and most of them show the basal cleavage.

Nearly all of the apatites contain inclusions of various kinds, but, unlike the zircons, symmetrical arrangements of them are uncommon. Some crystals are almost completely filled with cloud-like aggregates of opaque material. In others the inclusions form a dark cylindrical mass elongated parallel to the vertical axes of the crystals. In others there is a core of dense black with a dusky border which merges gradually into a clear outer zone. A rarer type of inclusion is a reddish brown clot with no darker core. Some of the crystals with cloud-like inclusions give pleochroic phenomena.

Included crystals the identity of which can be recognized, are less common. Those identified are tiny crystals of apatite, biotite, and zircon. Tube-like cavities occur fairly commonly. Some of these are arranged parallel to the vertical axis (Text-fig. 8, No. 3). Others are at right angles to it. In some crystals there is a symmetrical arrangement of the tubes as noted by Turner in apatites from some of the diabases he studied. Colourless bubbles are to be seen in most apatite crystals. Generally they are distributed in a haphazard way, but in a few they are more abundant in the centre, in a zone elongated parallel to the "c" axis (Text-fig. 6, No. 15).

In all the granites examined the apatites show the following characteristics: (*a*) Great variation in size; (*b*) simple crystallographic habit; (*c*) inclusion of minerals of several species; (*d*) rounding and corrosion of the crystals.

Titanite also was found in all granites examined. Generally it occurs in brown, wedge-shaped crystals, but there are also crystals which resemble monazite in form (Text-fig. 10, No. 15). It is usually possible to find a fragment on which the optical axial angle can be determined. Titanite crystals contain reddish-brown clots and also include recognizable crystals of apatite and zircon (Text-fig. 10, Nos. 18, 19). No regular arrangement of inclusions was recognized in any of the crystals examined.

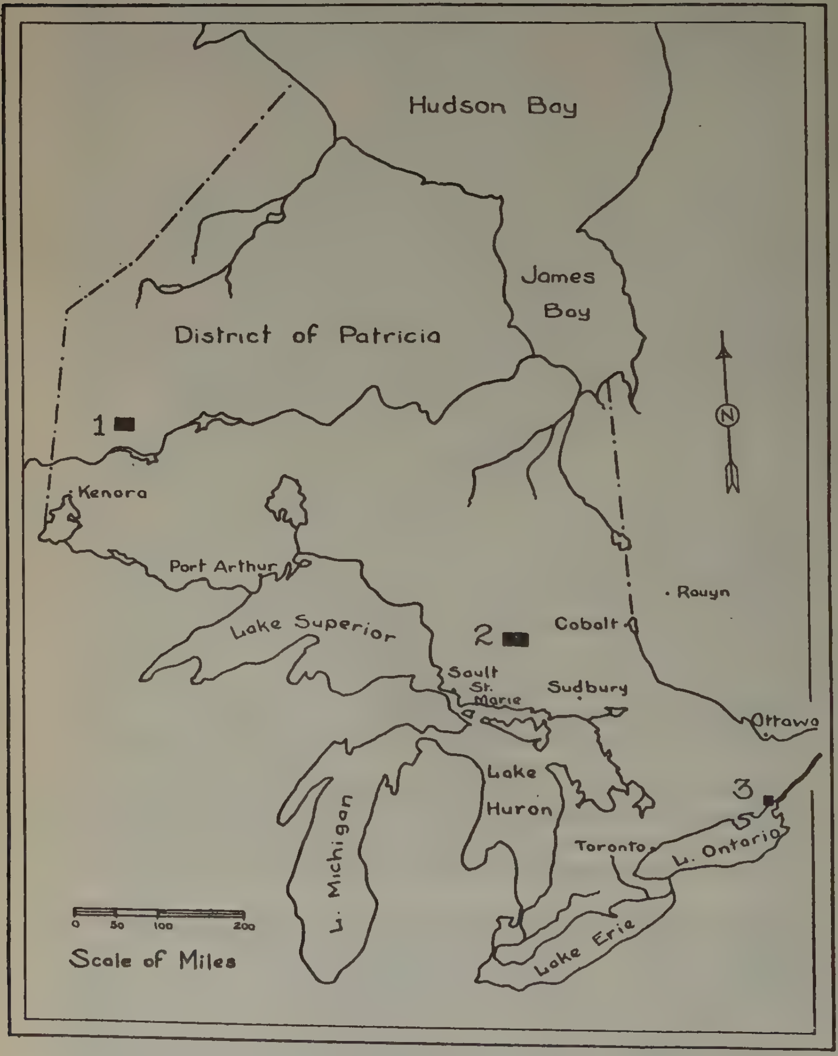
Rutile is abundant in some of the granites. Many of the crystals are euhedral; in some the corners are rounded. (Text-fig. 11, Nos. 10, 11.) The colour, elongated habit of the crystals and striations parallel to the elongation make the recognition of the mineral easy.

Other minerals occurring in the concentrates are hornblende, biotite, epidote, augite, fluorite, magnetite, ilmenite, pyrite and pyrrhotite. Some of these undoubtedly were introduced; others are so commonly present in all rocks that they cannot be considered of any diagnostic value.

The characters of the heavy accessories of some of the granites examined will be described in detail and the similarities and differences pointed out.

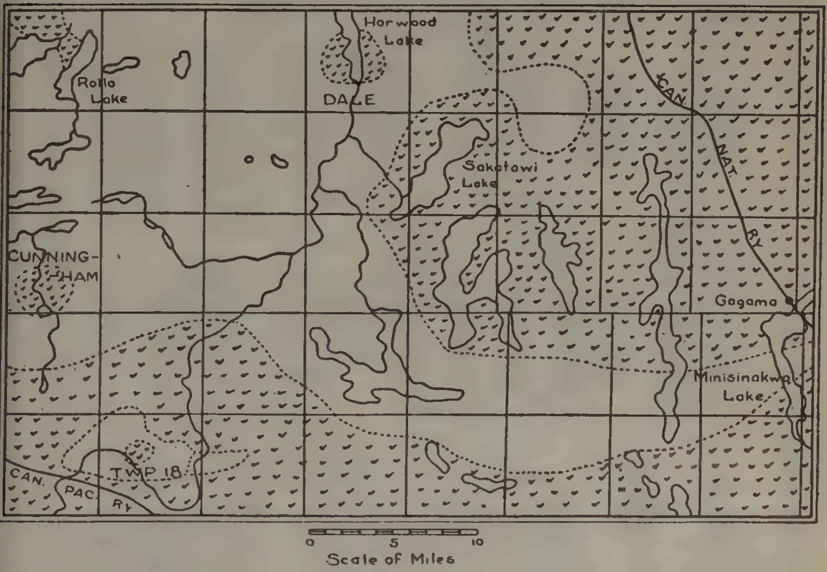
Detailed Descriptions.

Granite from the batholith at Red Lake in North-Western Ontario (Text-fig. 1), examined by N. D. Runnalls, was found to contain



Text-fig. 1.—Map of Ontario showing locations of (1) Red Lake Area; (2) Swayze-Woman River Area; (3) Kingston Mills.

zircon, apatite, titanite, epidote, rutile, and titaniferous magnetite as heavy accessories. The zircons are of the two varieties described above: buff-coloured ones are more abundant than clear ones. The buff zircons (Text-fig. 3, Nos. 1–7) seem to have the unit prism terminated by unit pyramid faces; a few have steeper pyramid faces as well. Inclusions in them have the appearance of small zircons somewhat rounded. The clear zircons (Text-fig. 3, Nos. 8, 9) are quite limpid. They are smaller than the buff variety, show the simple unit pyramid and unit prism combination, and have cavities that appear to be negative crystals.



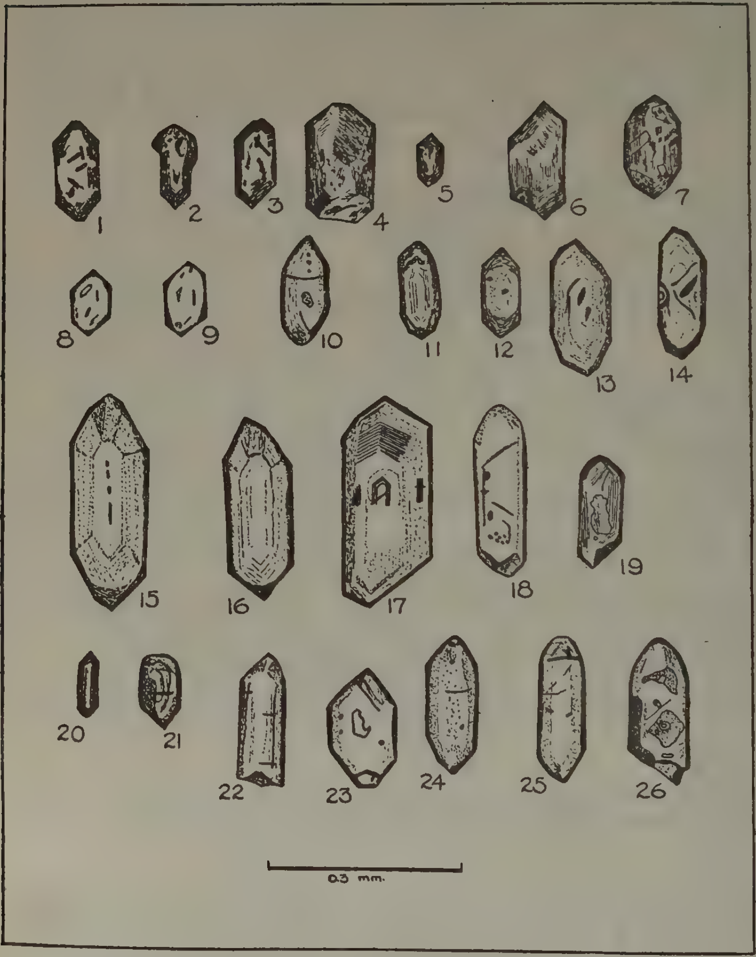
TEXT-FIG. 2.—Geological Map Swayze-Woman River Area, from Map 1933 (*a*) Ontario Department of Mines. Granite areas shown in pattern.

Apatite crystals from this granite also are of two kinds. Some of them are clear excepting for rod-shaped, pale pink inclusions in the centres of the crystals, parallel to the vertical axis. (Text-fig. 6, Nos. 1, 2.) Other crystals are clouded with tiny black specks, but, in all cases, the outer shell of the crystal is clear. (Text-fig. 6, Nos. 3, 4.) Both types have rounded edges.

Titanite is of a brownish red colour and no well formed crystals of it were seen.

Only one grain of rutile was found. It is reddish in colour, untwinned, but characteristically striated.[1]

The Swayze-Woman River area lies west of the town of Gogama on the Canadian National Railway and north of the Canadian Pacific Railway. (Text-fig. 2.) The area from which specimens were collected is approximately 50 miles long in an east–west direction and 30 miles



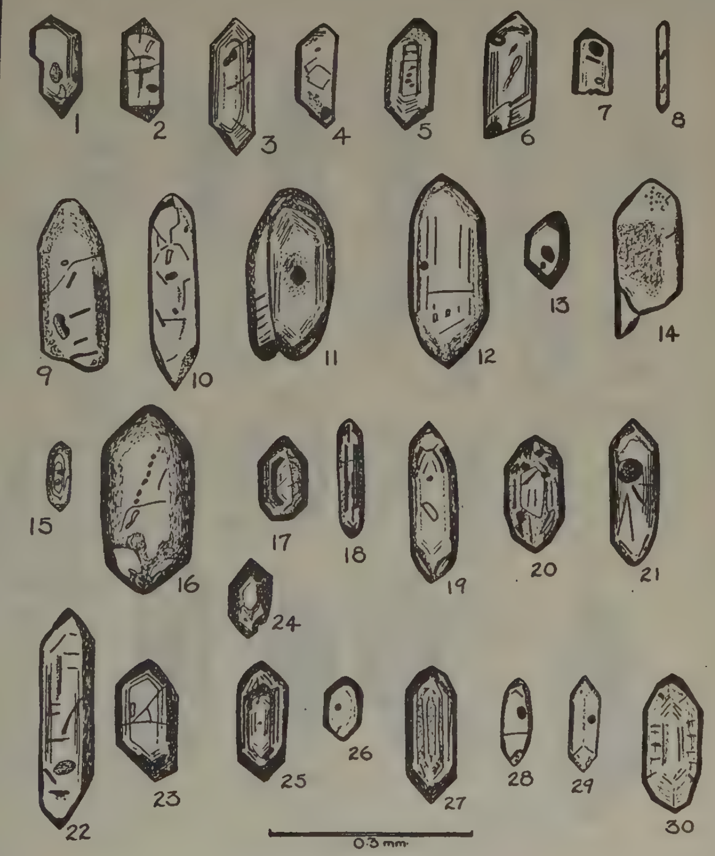
TEXT-FIG. 3.[2]

---

[1] N. D. Runnalls, "Mineralogical Variation in the MacKenzie Island Batholith, Red Lake, District of Patricia," *Rept. to the National Research Council of Canada*, 1933, 85–6.

[2] For explanation, see p. 211.

north and south. Geological examinations made are of a reconnaissance nature: so far only one kind of granite has been recognized. The granite cuts volcanic rocks that have been called Keewatin and sediments that have been assigned to the Timiskamian series. In both cases correlation is entirely on lithological grounds.[1]

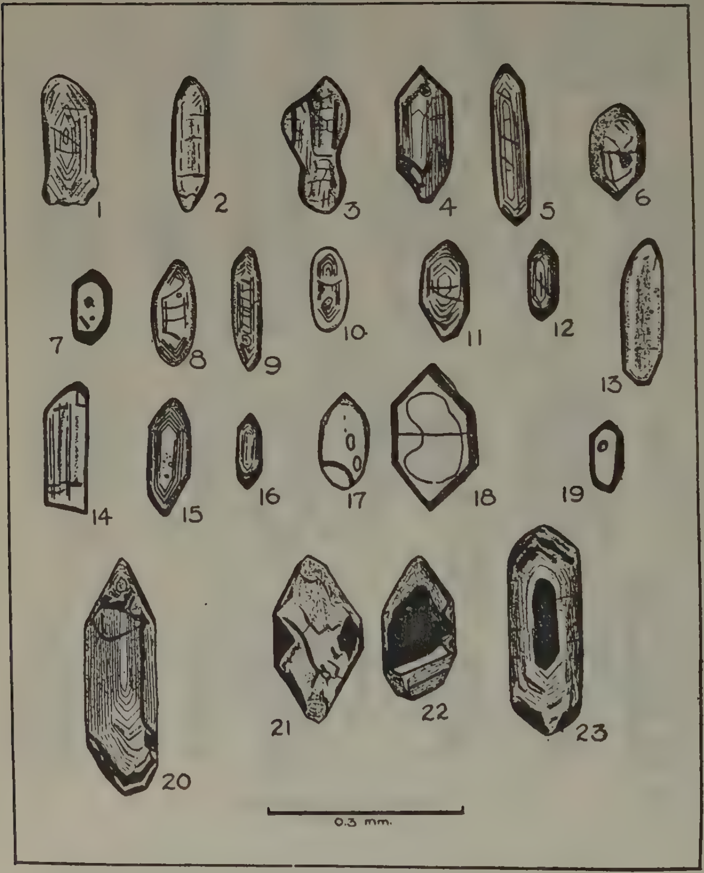


TEXT-FIG. 4.

---

[1] H. C. Rickaby, "Geology of the Swayze Area," *Ont. Dept. of Mines, 43rd Annual Rept.*, pt. iii, 1–36.
E. Thomson and R. C. Emmons, "Preliminary Report on Woman River Ridout Area," *Mem.* 157, *Geol. Survey of Canada.*

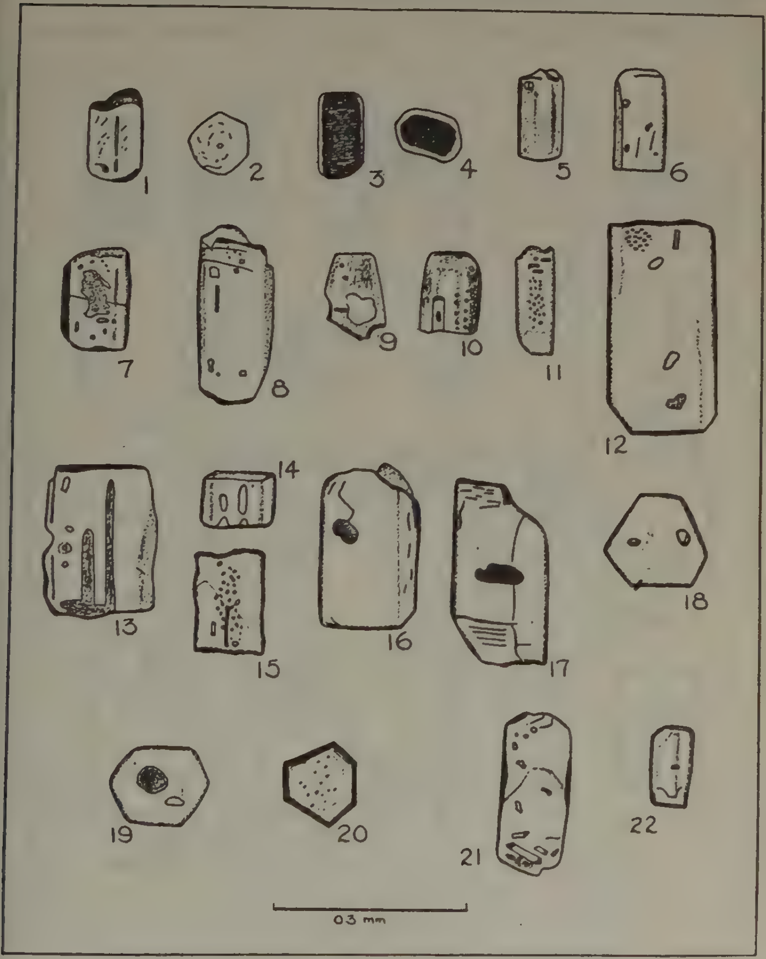
Granite from the north-west side of Rollo Lake in the extreme north-west corner of the area chosen (Text-fig. 2) is a massive, fresh, red, coarse-grained rock, made up of quartz, microcline, and orthoclase with minor amounts of perthite and some green hornblende. Muscovite, titanite, apatite, fluorite, and zircon are the accessory minerals. Kaolinization gives the feldspars a dusty appearance, and there is some sericite. The hornblende is partially altered to chlorite and epidote.



TEXT-FIG. 5.

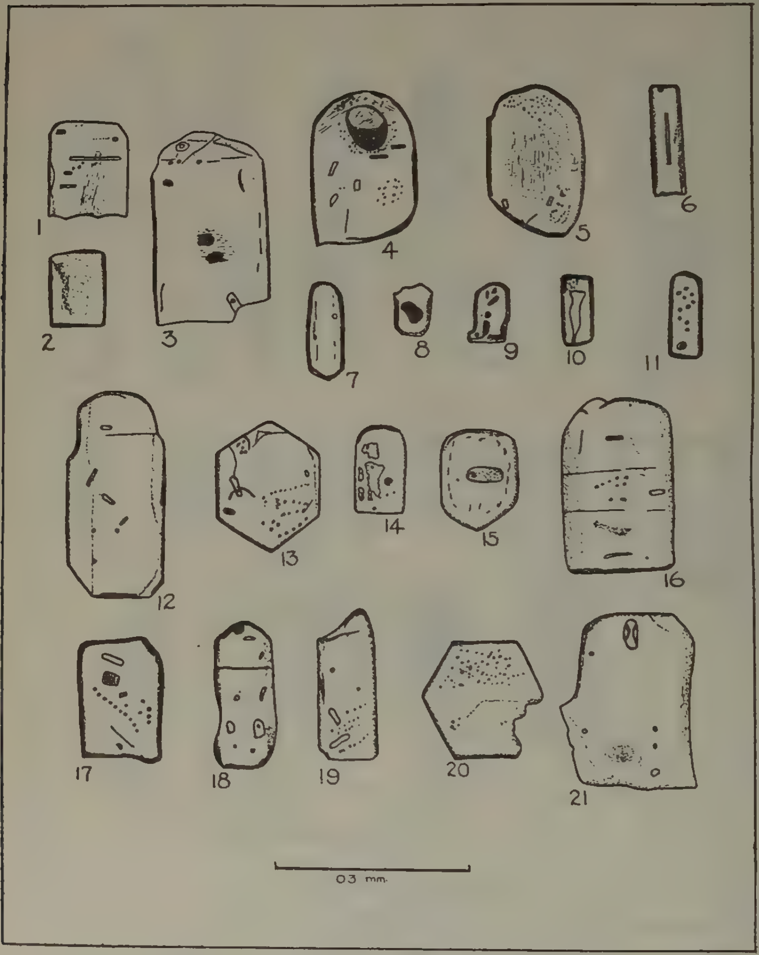
Zircons are not abundant in concentrates of heavy accessories of this granite, and those found are small. The larger ones are rounded. (Text-fig. 3, No. 10.) Both clear and tawny varieties occur.

Apatite crystals are abundant both as short stout forms and as acicular crystals. They contain all the types of inclusions described above. (Text-fig. 6, Nos. 7–10.) Titanite is also abundant. The crystals are well formed and include small zircons and apatites as well as undeterminable, reddish opaque material. (Text-fig. 10, Nos. 1–5.) Fluorite, epidote, biotite, muscovite, and hornblende are present.



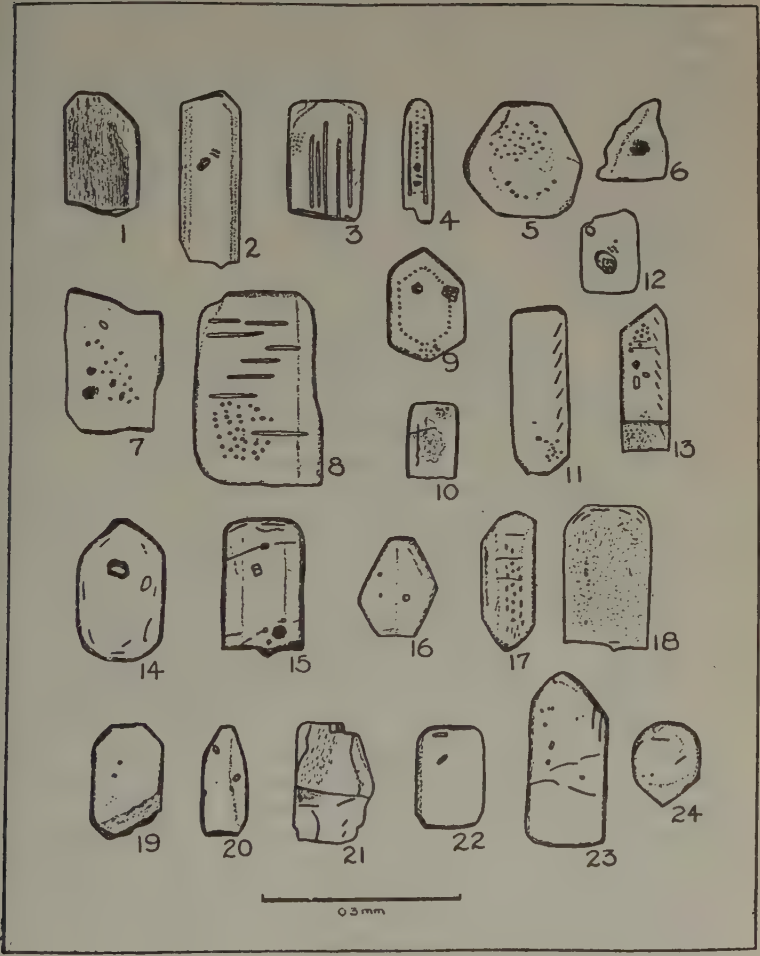
TEXT-FIG. 6.

Two miles north-west of Rollo Lake (Text-fig. 2) specimens were collected on the shore of Ridley Lake from granite very similar to that just described. It intrudes Keewatin flows and tuffs. Under the microscope it appears porphyritic; in composition it differs from the Rollo Lake granite in containing augite. In this granite both clear and tawny zoned zircons are present; the latter are unusual in being free from inclusions. The crystals differ widely both in shape and size. Apatite is abundant in simple, well-formed crystals and in irregular forms. Flakes of biotite, euhedral crystals



Text-fig. 7.

of apatite and zircon, cavities apparently gas-filled and some undeterminable opaque material are included within the apatite crystals. Well-formed titanite crystals are present, in which are enclosed tiny laths of apatite.



Text-fig. 8.

At a locality 16 miles south of Rollo Lake (Text-fig. 2), in the township of Cunningham, the granite is medium grained in texture. It is made up of quartz, orthoclase, microcline, and albite-oligoclase with minor amounts of hornblende and biotite. The accessory minerals are zircon, apatite, titanite, fluorite, ilmenite, and magnetite. Epidote, chlorite, sericite, and kaolin are alteration products of the primary minerals. There is a little pyrite. In the concentrates of the heavy accessories zircons both clear and tawny are relatively abundant. Both varieties show rounding of the crystal edges and many of the larger clear crystals are distorted. Within crystals of the tawny variety are reddish brown clots, scattered dust-like particles, and gas-filled cavities. (Text-fig. 3, Nos. 17–23.) The apatite crystals also vary in size and there are numerous pale blue, acicular ones, usually less than 0·1 mm. in length. Most of them have no inclusions, but in some there are reddish brown clots, smaller apatite crystals, and gas-filled cavities. (Text-fig. 7, Nos. 1–3.) The included apatite crystals are lath-shaped and usually have random orientations. In a few cases they seem to lie in the plane of the basal pinacoid of the host crystal.

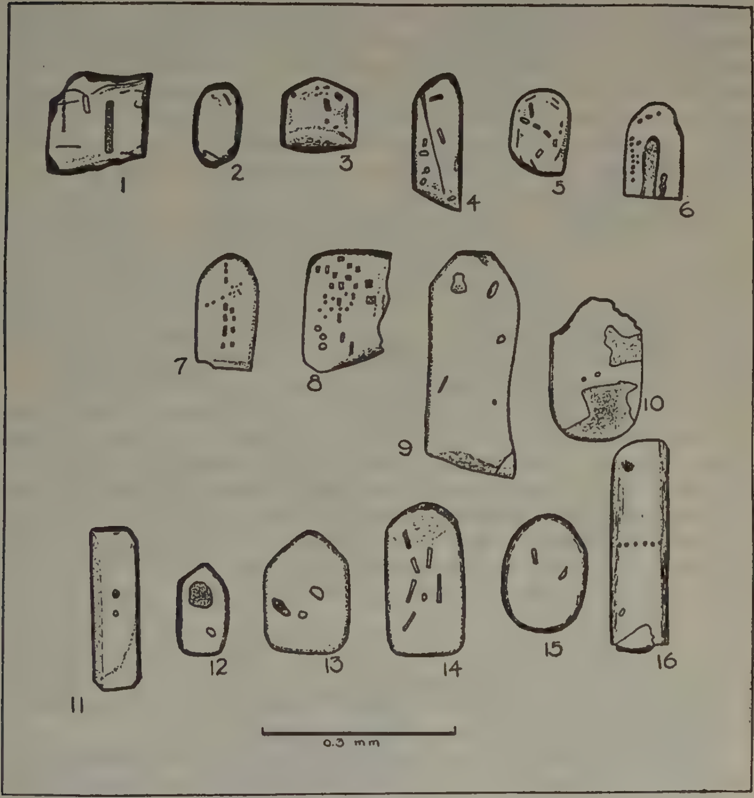
Titanite is more abundant than zircon in this granite, and is somewhat darker in colour than that of the Rollo Lake and Ridley Lake granites. (Text-fig. 10, Nos. 11–12.)

Still farther south, in Township 18 (Text-fig. 2), the Woman River batholith consists of a pinkish, medium-grained, finely foliated granite, which is made up of quartz, orthoclase, oligoclase, biotite, and small amounts of augite. As accessories it has titanite, magnetite, apatite, zircon, and hornblende.

Crystals of zircon (Text-fig. 4, Nos. 25–30) and apatite (Text-fig. 8, Nos. 14–17) from this granite are similar to those just described; the titanite crystals (Text-fig. 10, No. 15) differ, however, in having fewer inclusions than have those from other localities in this area.

Fifteen miles east of Rollo Lake in the township of Dale (Text-fig. 2) the rock at Horwood Lake is a granodiorite which is massive, grey in colour, and fresh looking. It is porphyritic with phenocrysts of feldspar up to ½ in. in length, which under the microscope are found to be andesine. The groundmass contains andesine, orthoclase, perthitic intergrowths, hornblende, biotite, and abundant quartz. Chlorite, sericite, and epidote are the alteration products present. Rutile, zircon, apatite, titanite, and magnetite were found in the concentrates of heavy accessory minerals. Rutile is abundant in crystals which are apparently combinations of the prism and pyramid, but many of them are rounded. Both acicular and nearly equidimensional types occur, all of which have characteristic striations. Zircon is less abundant than rutile. Most of the smaller crystals are perfect euhedra; the larger ones are rounded. (Text-fig. 5, Nos. 4–10.) Apatite is less abundant than it is in the granites previously described, but the forms are similar. (Text-fig. 9, Nos. 10–16.) Inclusions of reddish and black opaque material are present in most of them. In one basal cleavage plate a perfect euhedron of zircon was observed. Titanite occurs in large, irregular, deep brown crystals.

Nine miles south of Horwood Lake a sample was collected from islands near the outlet of Sakatawi Lake, in the south-east corner of Marion township (Text-fig. 2). The rock is a greyish to pinkish granite, which consists of quartz, microcline, orthoclase, oligoclase, perthitic intergrowths, hornblende, and biotite with small amounts of alteration products—sericite, chlorite, and kaolin. The heavy accessories in the concentrates are zircon, apatite, titanite, and magnetite. No clear zircons were obtained from this rock. (Text-fig. 5, Nos. 11, 12, 14–16.) The apatites show the greatest variety of inclusions, practically all possible types occurring. (Text-fig. 8, Nos. 1–13.) Many of the crystals are of the dusky type, with dust-like inclusions disseminated through them. Similar apatites have



TEXT-FIG. 9.

been reported from granodiorite in France[1] and from granite in England.[2]

In the south-east corner of the area, granite from the north shore of Minisinakwa Lake, near Gogama, was collected, and a second specimen 6 miles farther south on the east side of the lake. It has been suggested that the northern granite is older than the southern one, but both have been classed as Algoman in age.[3]

The northern one shows a distinct foliation. It contains quartz, orthoclase, oligoclase, biotite, and hornblende with zircon, apatite, titanite, and magnetite as accessory minerals. The feldspars have been severely altered to sericite and kaolin and the ferro-magnesian constituents are chloritized. Epidote is also present. Both clear and zoned zircons, most of which are rounded (Text-fig. 4, Nos. 9–11), occur. Apatites are plentiful both as acicular and stout crystals. Inclusions in them are similar to those in apatites from other granites. (Text-fig. 7, Nos. 4, 5.)

The southern and assumed younger phase is a massive pink to grey rock composed of quartz, orthoclase, microcline, oligoclase, and biotite. Alteration is of the same kind as in the granite just described, and seems to be as severe. The zircons are exceptional in the perfection of their crystal forms, and one acicular crystal of the clear variety is particularly well formed. (Text-fig. 4, Nos. 1–8.) In other respects the inclusions are similar to others described.

The rounding of the crystals of zircon in the foliated granite and the sharpness of the forms in the massive granite are features that deserve more detailed study. Mackie noted similar phenomena in his study of the heavy accessory minerals of Scotland, and came to the conclusion that rounding of zircons occurs only in granites, the foliation of which is due to movements before complete consolidation, and that the zircons are not rounded even in foliated granites if the foliation is the result of movements subsequent to complete consolidation.[4]

There is insufficient information in the case of the Minisinakwa granite upon which to base any conclusion as to the cause of the rounding, but there is no field evidence that the foliated and massive granites are of different ages.

In Eastern Ontario granite is abundantly exposed at many places. Much of it is foliated and was formerly thought to be older than the massive type. It is now generally believed to owe its foliated character either to the inclusion and nearly complete digestion of Grenville sediments or possibly to plastic flow during deformation prior to its complete consolidation. There is no conclusive evidence of a difference in age between the foliated and massive types.

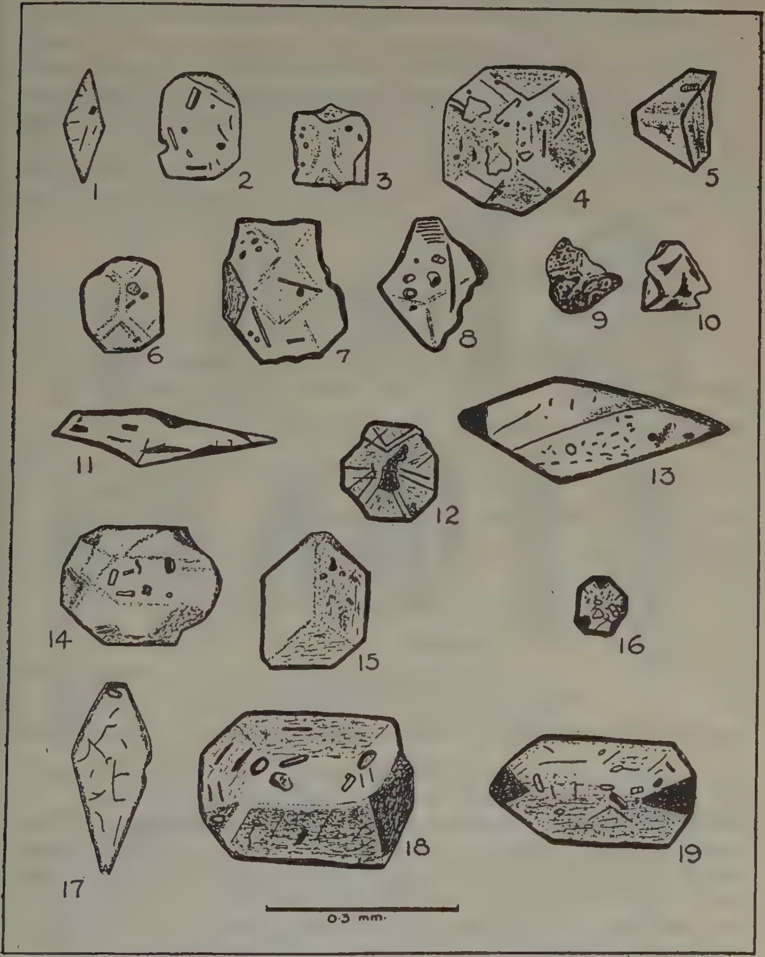
---

[1] J. H. Taylor, "The Mountsorrel Granodiorite," GEOL. MAG., LXXI, 1934, 7–8.

[2] B. Simpson, "The Dusky Apatites of the Eskdale Granites," ibid., LXX, 1933, 375.

[3] H. C. Laird, "Geology of the Three Duck Lakes Area," *Ont. Dept. of Mines, 41st Ann. Rept.*, pt. iii, 1932, 19–20.

[4] W. Mackie, "The Heavier Accessory Minerals in the Granite of Scotland," *Trans. Edin. Geol. Soc.*, xii, pt. i, 1928, 26.

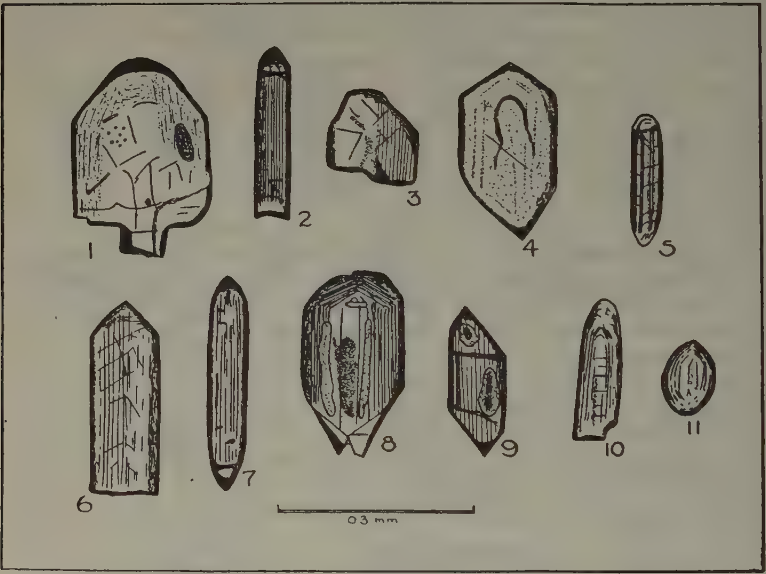


TEXT-FIG. 10.

At Kingston Mills (Text-fig. 1), 4 miles north of Kingston, the granite has only a faint foliation. It consists of orthoclase, microcline, quartz, hornblende, and biotite, with zircon, apatite, rutile, titanite and magnetite as the heavy accessories. The zircons obtained on concentrating the pulverized rock are relatively abundant. Both limpid and tawny varieties were found; all the latter are rounded. Among them is an hourglass form, not seen elsewhere. (Text-fig. 5, No. 3.) Rutile is of the same type as that previously described. Apatite is very plentiful, but few perfect crystals were seen. Usually it occurs in bluish green and clear colourless fragments.

SUMMARY AND CONCLUSIONS.

All the granites of these various localities contain zircon, apatite, and titanite. In some, rutile was recognized, but it does not occur abundantly in any, and examination of more material may show that it is present even in those granites in which it has not yet been found. The crystal habits of the heavy accessories vary widely, and in only one locality, Minisinakwa Lake in the Woman River area, was any unique characteristic recognized. In concentrates from the samples from that granite acicular zircons were found.



TEXT-FIG. 11.

Mackie described acicular zircons from the Scottish granites, which he considers represent "the residual zircon substance crystallizing by itself in the absence of definite nuclei, in the last stage of consolidation".[1]

---

[1] W. Mackie, op. cit.

The similarity of the accessories of all the granites examined might be considered as evidence of a single widespread granitic invasion, were it not for the fact that the accessories found in these granites are similar to those that occur in many other granites which are evidently of quite different age. Even in the habits of the accessories the variations within individual samples are as great as those between granites of widely separated areas and of entirely different ages. Thus the zircons figured by Ghosh from the granites of Cornwall[1] (Text-fig. 5, Nos. 20–23) are not unlike several of those figured from the granites examined in the present study.

Hence, as far as the results of this limited investigation go, no unique characteristics of any of the granites can be recognized which might form criteria for correlation of or differentiation between the various masses.

Explanation of Illustrations.

Text-fig.

3.—Zircons.

Nos. 1–7. Buff-coloured and zoned, from granite at Red Lake.
Nos. 8, 9. Clear and not zoned, from granite at Red Lake.
No. 10. Clear and not zoned, from granite at Rollo Lake, Swayze-Woman River Area.
Nos. 11–14, 15, 16. From granite at Ridley Lake, north-west of Rollo Lake.
Nos. 17–23. From granite in Cunningham Township, Swayze-Woman River Area.
Nos. 24–26. From granite gneiss at Minisinakwa Lake. The crystals are rounded.
Nos. 18 and 19 contain reddish brown clots and No. 18 also has tiny cavities. Tawny varieties.
No. 21. Tawny variety, contains clouds of opaque dust.
No. 22. Clear variety.
No. 26. Contains a reddish brown inclusion.

4.—Zircons.

Nos. 1–8. From massive granite at Minisinakwa Lake.
Nos. 9–14. From granite gneiss at Minisinakwa Lake.
Nos. 15, 16. From granite at Groves Lake, 6 miles east of Minisinakwa Lake. No. 15 is clear.
Nos. 17–22, 24. From the granite in township 18. Woman River stock. Clear crystals like 22 are commonly distorted.
Nos. 23, 25–30. From the granite in township 18, Woman River batholith.
Nos. 4 and 8 are clear crystals. No. 8 is an unusual acicular type.
Nos. 1–3, 5–7 are tawny zircons with various types of inclusions.
No. 10. Clear round zircon.
Nos. 9 and 12 are tawny and zoned.
No. 13 is a distorted form.
No. 16. Buff-coloured. Central part clear and comparatively free of inclusions. Margin shows closely spaced zoning which obscures the brilliant colouring of the crystal. The great variations in size of zircons in the granite at Groves Lake are illustrated.
No. 27 is unusual in being zoned but having no visible inclusions.

---

[1] P. K. Ghosh, "The Mineral Assemblages of the Falmouth Granite (Cornwall)," *Proc. Geol. Assoc., London*, xxxix, 1928, 201–220.

TEXT-FIG.

5.—Zircons.
 Nos. 1–3, 17, 18, 19. Kingston Mills granite.
 Nos. 4–10. Horwood Lake granite.
 Nos. 11, 12, 14–16.. Sakatawi Lake granite, Woman River Area.
 Nos. 21–23. From Plate No. 23, *Proc. Geol. Assoc. London*, xxxix, 3, (1928), by P. K. Ghosh. Falmouth, Cornwall, granite.
 No. 18. Clear crystal with large cavity.
 No. 3. Peculiar hour-glass form.

6.—Apatite.
 Nos. 1–4. From Red Lake granite.
 Nos. 5–10. From Rollo Lake Granite Swayze-Woman Lake Area.
 Nos. 11–20. From granite from Ridley Lake, north-west of Rollo Lake.
 Nos. 21, 22. Apatite crystals from Cunningham township, Swayze-Woman River Area.
 Nos. 1 and 2. Elevation and plan of crystal with cylindrical inclusion.
 Nos. 3 and 4. Apatites with dark aggregate in centre and clear outer shell.
 No. 5 is a “ dusky ” apatite. Large crystals such as No. 8 are rounded.
 Nos. 7, 8, 9 contain inclusions of bright red pleochroic material.
 No. 12. Common simple form.
 No. 13. Apatite crystal with inclusions of biotite.
 Nos. 14–15. Apatite crystals with cavities.
 Nos. 19–20. Basal sections.
 No. 22 has smaller apatites with random arrangement within the larger one.

7.—Apatites.
 Nos. 1–3. From granite at Cunningham Township.
 Nos. 4–5. From the granite gneiss at Minisinakwa Lake.
 Nos. 6–11. From the massive granite at Minisinakwa Lake. These crystals are pale blue.
 Nos. 12–21. From granite at Groves Lake, 6 miles east of Minisinakwa Lake.
 No. 1. Contains smaller apatites lying in the plane of the basal pinacoid.
 No. 3 contains small apatite crystals, cavities, and a clot of opaque material with two darker cores.
 Nos. 4 and 5 show rounding. No. 4 contains small apatite crystals and a clot of opaque material.
 Nos. 8 and 9 have opaque inclusions, No. 10 a cavity.
 No. 13 and 20 basal plates.
 No. 15 has a zone of inclusions in it.

8.—Apatite.
 Nos. 1–13, 18. Apatites from granite at Sakatawi Lake.
 Nos. 14–17. Apatites from granite in Township No. 18 (Woman River batholith).
 Nos. 19–24. Apatites from small stock Township 18 (Woman River stock).
 No. 9. Basal plate showing zonally arranged inclusions.
 No. 3. Crystal contains cylindrical inclusions.
 Nos. 14 and 24 are rounded basal plates. These are common both in the granite of the batholith and that of the stock.

9.—Apatite.
 Nos. 1–9. Apatites from Kingston Mills granite.
 Nos. 10–16. Apatite from granite at Horwood Lake, Dale Township, Swayze-Woman River Area.
 No. 1 contains a foil of biotite.
 No. 13. A basal plate of apatite contains a well-formed zircon crystal.
 No. 15. Rounded basal plate. These are abundant.

10.—Titanite.
 Nos. 1–5. Titanite crystals from the granite at Rollo Lake, Swayze-Woman River Area.

TEXT-FIG.

10.—Titanite.

- Nos. 6–8. Titanite from the granite at Ridley Lake, north-west of Rollo Lake.
- Nos. 9, 10. Titanite from granite at Red Lake.
- Nos. 11, 12. Titanite from granite in Cunningham Township.
- Nos. 13–14. Titanite from granite at Groves Lake, Swayze-Woman River Area.
- No. 15. Titanite resembling monazite in habit, from Woman River batholith, Township 18, Swayze-Woman River Area.
- No. 16. Titanite from granite at Kingston Mills.
- Nos. 17–19. Titanites from granite at Sakatawi Lake, Swayze-Woman River Area.
- No. 7. Titanite including lath-shaped crystals of apatite.

11.—Rutile.

- Nos. 1–4, 6–9. Rutile from the granite at Horwood Lake, Swayze-Woman River Area.
- Nos. 5, 10–11. Rutile from granite at Kingston Mills.

On Certain Endocranial Structures in *Coccosteus.*

By EDWIN SHERBON HILLS, University of Melbourne.

(PLATE III.)

SINCE 1876, when McCoy described two specimens of tuberculated plates under the name *Asterolepis ornata* var. *australis*, placoderm remains have been known to occur in the Middle Devonian marine limestones of Buchan, Victoria, Australia. Some years later, another specimen was obtained from the Buchan limestones by W. H. Ferguson of the Geological Survey of Victoria, and was referred by Chapman (1916) to the genus *Phlyctaenaspis*. Chapman, regarding McCoy's specimens as cospecific with the new material, included all the remains in the species *Phlyctaenaspis australis* (McCoy), distinguishing the more complete specimen discovered by Ferguson as *P. australis* var. *confertituberculata* Chapman. As *Phlyctaenaspis* is a form typical of the Lower Devonian, its reported occurrence in the Middle Devonian seemed to warrant further investigation. I therefore undertook a re-examination of all the available material, which is now preserved in the National Museum, Melbourne, and spent some months in removing the matrix from Ferguson's specimen. The matrix is a hard carbonaceous limestone containing remains of *Spirifer yassensis* and other invertebrates, and it was found that dilute hydrochloric acid would dissolve away this matrix without seriously affecting the fish plates, although care had to be taken not to subject these to too long contact with the acid. When as much of the matrix as possible had been removed mechanically by grinding, the fossil was exposed by brushing the dilute acid on to the remainder with a camel-hair brush, and continually observing the result under a binocular microscope. Needles and fine scrapers were also used. Owing to the crushed and broken state of the thinner bone lamellae, certain parts of the fossil would not hold together when freed from the rock, and it was found necessary to examine small parts as they appeared, then continue the dissection, and repair any damage as well as possible afterwards. The essential parts of the fossil were thus observed and as much of the internal structure as possible made out on the broken edges. Sections were also ground along the middle line and at right-angles to this, in the anterior parts.

As a result of this examination, it became clear that the specimen obtained by Ferguson is not referable to *Phlyctaenaspis*, but to *Coccosteus*, and furthermore, that parts of the endocranium, which was superficially ossified in a similar manner to that of *Macropetalichthys* and the Acanthaspids described by Stensiö (1925, 1934), are preserved. It was these endocranial ossifications which presented so much difficulty in dissecting out the fossil, not only because they are usually extremely thin, but because they are broken, and impregnated with calcareous material which, in evolving carbon dioxide, tends to further break up the thin bone lamellae.

McCoy's type specimens were also examined, and I consider that it is impossible to state whether they are cospecific with the type of " *P. australis* var. *confertituberculata* " or not, or even to assign to them a generic name. The specimen forming the subject of this paper is, therefore, referred to a new species of *Coccosteus*, *C. osseus*.

Genus Coccosteus Agassiz.

Coccosteus osseus sp. nov.

Syn. *Phlyctaenaspis australis* var. *confertituberculata* Chapman, 1916.

Locality.—Buchan, Victoria, Australia.

Formation.—Middle Devonian marine limestones.

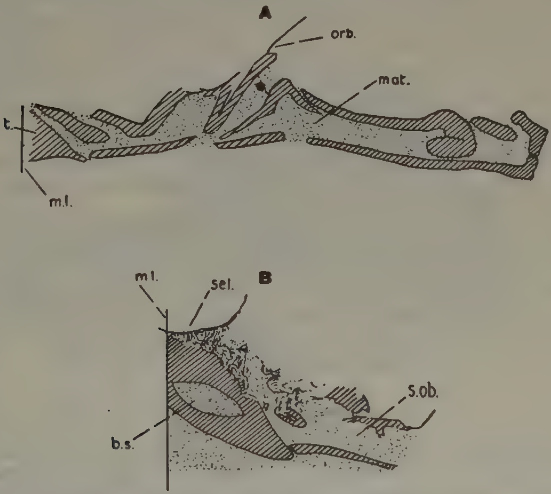
Diagnosis.—Endocranium in part superficially ossified; dermal cranial bones fused; posterior margin of nuchal plate projecting back beyond a line joining the fossae condylorum; ornament of smooth tubercles arranged in rows.

Description.

Dermal Cranial Bones.—The anterior roofing bones of the head are not preserved in the fossil, only that part remaining which in other species is composed of the nuchal, para-nuchal, marginal, post-orbital, post-marginal, and parts of the central plates. The pre-orbital, pineal, rostral, and parts of the central plates are missing. The plates are ornamented with smooth tubercles which are arranged in rows parallel to the sensory canals. The arrangement of the canals is that typical of *Coccosteus*, and calls for no comment, except to note that the small commisure near the fossae condylorum on the para-nuchals, between the sensory canals diverging from near these points, is merely a shallow groove and not a deep canal like the main sensory tracts. The foramina interpreted by Obrutschew

(1929) as the foramina through which the ducti endolymphatici opened on the dorsal surface are situated at the posterior ends of the sensory canals which run parallel to the sides of the nuchal plate, a condition differing slightly from that in *C. trautscholdi* (Eastm.) (see Obrutschew, 1929) and *C. decipiens* Ag. (see Heintz, 1931) in which the foramina are not connected with the sensory canals. The arching of the cranial roof is well shown in the specimen, although a certain amount of fracturing has occurred, so that the arching now shown is less than the true amount.

The partial ossification of the endocranium is sufficient to separate the species from all other known members of the genus *Coccosteus*, although it is to be expected that as better preserved material is discovered in other parts of the world, such a distinction will break down. The cranial shield bears a strong general resemblance in shape, size, and ornament, to *C. decipiens* Ag., but it is readily distinguished from *C. parvulus* Huss. and Bryant (1918) and from *C. canadensis* Woodward (1892) by the shape of the nuchal plate, which in these species has a concave posterior border like *Dinichthys*. *C. trautscholdi* (Eastm.) is larger and differs in details such as the shape of the nuchal plate and the irregular arrangement of the tubercules. *C. fletti* Watson (1932) differs from *C. osseus* in the



Text-fig. 1.—A. Section across the subocular shelf of the left side of *Coccosteus osseus*, immediately anterior to the fenestrae hypophyseos. *Mat.*, matrix between the dorsal and ventral surfaces of perichondral bone; *m.l.*, middle line; *orb.*, wall of the orbit; *t.*, thickened part of the subocular shelf near the sella turcica. B. Section across the subocular shelf of *Coccosteus osseus*, a little more posteriorly than A.; *b.s.*, blind sac-like pit; *m.l.*, middle line; *sel.*, edge of the sella turcica; *s.ob.*, subocular shelf.

same manner as it differs from *C. decipiens*, so far as is known, and insufficient is known of the head of other *Coccosteus* species to enable comparisons to be made.

Endocranium.—The manner in which the endocranium is ossified in *Coccosteus osseus* resembles the conditions in *Macropetalichthys* (Stensiö, 1925) and certain Acanthaspids (Stensiö, 1934). The dorsal surface of the endocranium, as far as can be made out, was not ossified at all, but the ventral surface, the canals through the cartilage for nerves and blood vessels, the labyrinth cavity, and probably the orbito-temporal parts of the cavum cerebrale, were lined with thin substitution bone. Where the floor of the endocranium was thickened, or projected as a lamina beyond the lateral walls of the cavum, as in the sub-ocular shelf, the thickened parts were either lined both above and below with thin bone between which the cartilage remained, or were replaced by bone entirely, as in the vicinity of the presumed fossa hypophyseos (see Text-fig. 1). In the ethmoidal region there is no indication of a dorsal ossification of the endocranium, and, as all traces of the cartilage were removed during fossilization, it cannot be decided whether or not there was an anterior fontanelle of any description present, as in *Macropetalichthys* and the Acanthaspids.

Owing probably to the decay of the cartilage before and during fossilization, the ossified floor of the endocranium has, especially in the more anterior parts, been pushed up close to the dermal roofing bones. In this respect, as may be judged from the condition of the orbits, the right side of the fossil has suffered less distortion than the left.

Ethmoidal Region.

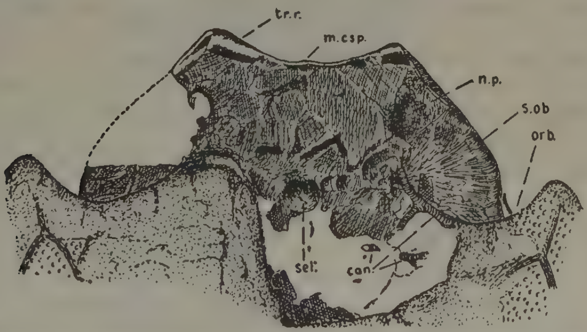
The most anterior part of the endocranium preserved (and there is no indication of the former presence of any more anteriorly situated structures) consists of a ventral ethmoidal plate forming a continuation of the floor of the orbito-temporal region and of the sub-ocular shelves. The anterior margin of this ethmoidal plate is concave in plan, with a small median cusp, and is thickened on the dorsal surface, forming a transverse ridge which is traversed laterally by a minute canal.

The ethmoidal region of the endocranium of *Coccosteus* thus clearly bears a strong resemblance to the ethmoidal region of the Acanthaspid genus described by Stensiö (1934), although Stensiö does not show an anterior thickening in his figures (this nevertheless being suggested in his pl. xiv, fig. 1), and the lateral openings of the transverse canal are larger in the Acanthaspid.

Traced laterally and posteriorly, the ethmoidal plate in *Coccosteus* expands so as to form a sub-ocular shelf on either side. This expansion is not shown in the Acanthaspids, but Stensiö recognized the fact that the ethmoidal plate in those forms is continuous with the sub-ocular shelves, and he deduced that upon the ethmoidal plate, anterior to the eyes, the olfactory organs must have lain "rather close to each other, and with their external openings directed straight forwards, as in *Pholidosteus*".

In Stensiö's specimens, the dorsal side of the ethmoidal plate was not visible, but because of the absence of a dorsal cover to the plate in *Coccosteus*, certain structures are visible which are not shown in the Acanthaspids.

Thus, near the antero-lateral corners of the plate, there are situated two sharply defined, steep-walled elliptical pits, no trace of which is to be seen on the ventral surface, and which therefore represent excavations within the plate itself. The floor of each pit is very thin, but is not perforated by foramina, and I can only suggest that in these pits lay the olfactory capsules.



Text-fig. 2.—Sketch of the dorsal surface of the anterior parts of the endocranium of *Coccosteus osseus*. × 1½ approx. Dermal cranial bones stippled, endocranium lined; *can.*, canals, probably for blood vessels; *m.csp.*, median cusp on the ethmoidal plate; *n.p.*, nasal pit; *orb.*, orbit; *sel.*, sella turcica; *s.ob.*, subocular shelf; *tr.r.*, transverse ridge at the anterior end of the ethmoidal plate.

The position of the pits agrees with that of the olfactory capsules in *Dinichthys* as interpreted by Stetson (1930) and Heintz (1932, fig. 84), and their size, although somewhat small, is comparable with that of the olfactory pits in *Pholidosteus* (Stensiö, 1934, pl. v), and with the capsules in *Dinichthys*.

Watson's suggestion (1934) that the capsules in *Coccosteus* were quite close to each other and separated by the "median superognathal", is not in agreement with the above interpretation, and it should also be noted that in *Pholidosteus* the pits were close together (Stensiö, 1934).

However, *Coccosteus* is much more closely related to *Dinichthys* than to *Pholidosteus*, and no other more likely position of the olfactory capsules than that suggested above can be inferred from the structure of the endocranium of *Coccosteus osseus*. It may be noted that if the external nasal openings in *Coccosteus* were situated between the rostral and post-nasal plates, as is usually assumed, these openings must have been closer to the pits than would appear at first sight from a reçonstruction of the flattened head, for in life the rostral plate was nearly vertical.

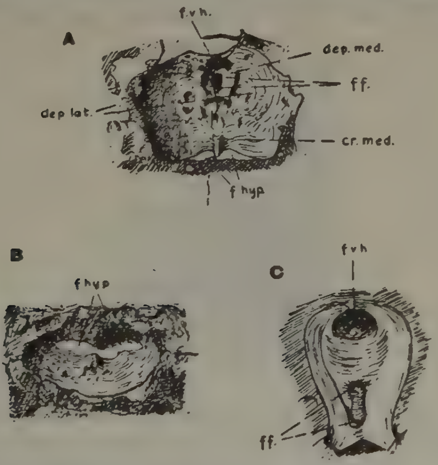
Whatever the function of the pits may have been, it will be clear from what follows that the olfactory tracts at least, if not the capsules themselves, must have been supported by the ethmoidal plate.

Orbito-Temporal Region.

Situated in the middle line between the eyes there is in *C. osseus* a deep pit in the endocranial floor (see Text-fig. 2). From the floor of this pit, at its anterior end, two short canals, separated by a thin bone lamella, run downwards and forwards to open on the under surface of the endocranial floor, which in this region is thickened and composed of solid bone (see Text-fig. 1). I believe, for reasons given below, that this pit is the sella turcica (fossa hypophyseos), but the significance of the details of its structure is somewhat doubtful. Stensiö found that in the Acanthaspids the endocranial floor is pierced by an unpaired short median canal which opens on to the ventral surface through an oval foramen, called by him the fenestra hypophyseos. On each side of the dorsal opening of the canal there is a " broad but short depression ", that is to say the canal leads upwards to a bilobed pit, which Stensiö regards as either the bottom of the fossa hypophyseos or a dorsal dilatation of the fenestra hypophyseos. There can be little doubt that these structures are homologous with the pit and paired canals in *Coccosteus*, although there is the significant difference that in *Coccosteus* there are two canals—or one divided by a median partition—leading from the fossae to the ventral surface, although in a poorly preserved specimen it is quite possible that the duplicate nature of this canal would not be observable. Furthermore, the ventral fenestrae are not immediately beneath the sella turcica, but open anteriorly to it. Further discussion may be postponed until the details of this region have been described.

The presumed sella turcica is a steep-walled, rounded pit, on the floor of which a small ovoid median depression surrounded by a low rim, occurs in the posterior third (dep. med., Text-fig. 3A, shown enlarged in Text-fig. 3C). In the middle of this depression is a further small pit, from which two minute openings lead into the bone below, one running forwards and downwards, the other backwards and downwards (*f.f.*, Text-fig. 3). On either side of this median ovoid depression the floor of the sella turcica is hollowed out to form shallow basins (*dep. lat.*, Text-fig. 3A), which extend forward to a more elevated part of the floor of the pit occupying the anterior third. This elevated part slopes down to the openings of the paired canals leading from beneath the anterior wall of the pit to the ventral surface of the endocranium (*f.hyp.*, Text-fig. 3A), and is divided by a median ridge continuous with the lamina of bone that separates these canals. In addition, each canal itself shows evidence of a dual structure, being slightly deeper mesially and slightly shallower laterally (Text-fig. 3B).

In the posterior wall of the sella turcica, in the middle line, is a backwardly directed foramen (*f.v.h.*, Text-fig. 3C), and the floor of the sella has numerous minute foramina, usually at the terminations of small ridges. The floor of the cavum cerebrale rises as the presumed sella turcica is approached on either side, and it is probable that the posterior edge of the fossa represents an ossification of the acrochordal cartilage.

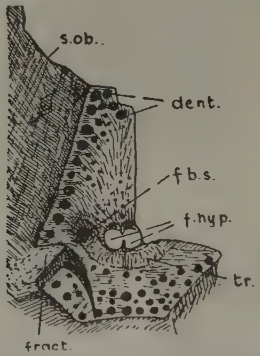


Text-fig. 3.—A. Sella turcica of *Coccosteus osseus*. × 6 approx. *cr. med.*, median ridge on the floor, continuous with the lamina dividing the hypophysial canal into two; *dep. lat.*, lateral basin-shaped depressions; *dep. med.*, median ovoid depression; *f.f.*, small foramina in the floor of the ovoid depression; *f.hyp.*, dorsal openings of the hypophysial canal leading to the ventral surface; *f.v.h.*, foramen leading to the vena hypophyseos. B. Sella turcica of *Coccosteus osseus*, seen from behind, and showing the dual nature of each half of the hypophysical canal; *f.hyp.*, Matrix stippled. C. Median ovoid depression in the floor of the sella turcica, greatly enlarged; *f.f.* and *f.v.h.* as in 3A above.

From this description, it would appear that the pit in question bears certain general resemblances to the pituitary fossa of fishes, especially the elasmobranchs, but in details there are distinct differences (see Allis, 1914; Goodrich, 1930). The small foramen in the posterior wall of the fossa seems most likely to have led to the pituitary vein, and there are indications of a transverse canal behind the fossa, which may have transmitted this vessel.

The shallow depressions occupying the posterior two-thirds of the floor of the fossa (*dep. lat.*, Text-fig. 3A) clearly supported a pair of sac-like structures dependent from the ventral surface of the brain. These may have been the right and left halves of the saccus vasculosum. The interpretation of the other structures depends on whether the anterior canals leading to the ventral surface of the endocranial floor were hypophysial fenestrae or not.

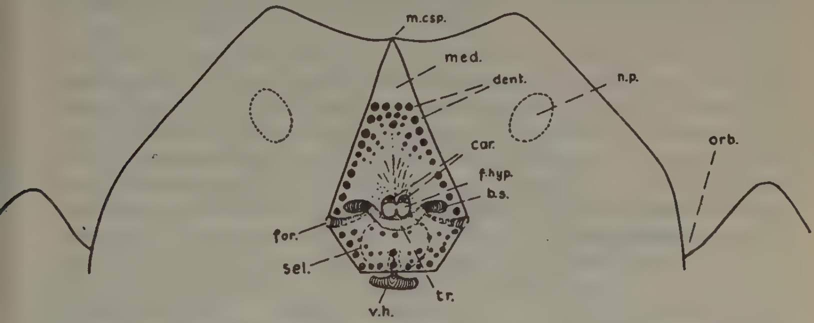
I know of no case in which the hypophysis, either in embryonic or adult stages, was paired, except perhaps in *Pteraspis* (Stensiö, 1932). In view of the complexity of the pituitary bodies in modern forms, the fact that median unpaired structures such as the pineal bodies originated as paired outgrowths, and that other portions of the pituitary bodies are typically paired, I think the possibility cannot be neglected that those canals did transmit paired hypophysial outgrowths from the pharynx.



Text-fig. 4.—Sketch of the ventral surface of the endocranium of *Coccosteus osseus* in the neighbourhood of the fenestrae hypophyseos. The specimen is incomplete, and should be compared with the restoration given in Fig. 5. *dent.*, denticles; *f.b.s.*, fenestra leading to the blind sac-like pit of the right side; *f.hyp.*, fenestrae hypophyseos, separated by a lamina of bone; *fract.*, fracture in the bone; *s.ob.*, ethmoidal plate, the anterior edge being incomplete; this is continuous laterally and posteriorly with the subocular shelf; *tr.*, smooth tract of bone connecting the foramina leading to the sac-like pits.

As has been described, each of these canals shows evidence of a dual structure at its upper end, and it is therefore possible that if they transmitted hypophysial outgrowths, these outgrowths may have had adjacent to them structures comparable with the lobi inferiores. The median ovoid depression in the posterior third of the floor may mark the position of a blood-vascular sinus, connected with vessels through the two small openings in the floor of the fossa.

An alternative explanation is that the small median depression may have supported the posterior part of the hypophysia, and if this did not reach through to the roof of the pharynx, the anterior canals may have transmitted blood vessels, perhaps the internal carotids. Against this is the dual nature of each canal, their relatively large size, the fact that in these circumstances the hypophysis must have been very small, and the upward and backward course of the canals, as opposed to the more usual upward and forward course of the internal carotids. On the first hypothesis the carotids may be imagined as having reached the cavum cerebrale cranii by means of two small vertical canals (see Text-figs. 4 and 5), which lead from the upper side of the anterior (lower) ends of the presumed hypophysial fenestrae. These canals traverse the endocranial floor from the lower to the upper surface, but are somewhat smaller in relative size than the carotid foramina of modern elasmobranchs.



Text-fig. 5.—Diagrammatic reconstruction of the ventral surface of the anterior parts of the endocranium of *Coccosteus osseus*. × 2 approx. *b.s.*, blind sac-like pits, the form seen as in a transparency; *car.*, foramina leading upwards to the dorsal surface of the endocranium, perhaps for the internal carotid arteries; *dent.*, denticles on the thickened median portion, which formed the roof of the pharynx; *f.hyp.*, fenestra hypophyseos; *for.*, foramen leading to a transverse canal, shown as in a transparency; *med.*, median thickened denticulate portion; *m.csp.*, median cusp; *n.p.*, position of the nasal pits (on the dorsal surface); *orb.*, orbit; *sel.*, broken line showing the position of the sella turcica; *tr.*, smooth tract of bone extending between the sac-like pits; *v.h.*, vena hypophyseos.

On the ventral surface of the endocranial floor there are certain other structures adjacent to the presumed hypophysial fenestrae, for which I can suggest no very definite interpretation. Lateral to the fenestrae there is on each side a large foramen which leads upwards into a blind sac-like pit running laterally within the bone. A smooth tract of bone surface runs between these foramina posteriorly to the fenestrae hypophyseos, and it is clear that some strand of tissue or vessel ran from one foramen to the other beneath this smooth tract. What was the function of the pits and the connecting structure, I cannot suggest.

Text-figs. 4 and 5 show the details of the ventral surface of the endocranial floor from the neighbourhood of the fenestrae hypophyseos forwards. It will be seen that the median part was thickened, and projected beneath the general level of the plate of bone. The thickened region tapers forwards towards the cusp on the anterior margin, and is provided with regularly spaced denticles. This region clearly formed the dorsal surface of the pharynx, so that the interpretation of all the endocranial structures above described as appertaining only to the ventral plate of the endocranium must be correct.

On the nearly vertical edge of this median thickened portion of the ventral surface, lateral and somewhat posterior to the foramina leading to the sac-like pits, there is on each side a small ovoid foramen opening laterally, which leads into a transverse canal. Owing to the fact that the fossil was broken just where the canal of the right side had its exit, and that the left side was removed in preparation, the course of these canals is uncertain, but the right canal appears to run mesially, to enter the foramen leading to the sac-like pit; and thus also to approach the presumed carotid foramina (Text-figs. 4 and 5). The canals may therefore have transmitted those parts of the internal carotid arteries external to the cavum cerebrale, in a manner resembling the condition in *Macropetalichthys* (Stensiö, 1925). Foramina in a corresponding position in the Acanthaspid described by Stensiö (1934) lead upwards and mesially into a canal regarded as the opticus canal, which runs in a similar direction to the blind sacs in *Coccosteus*. These foramina are regarded by Stensiö as carotid foramina.

In comparing the ventral surface of the endocranium in *Coccosteus* with that of the Acanthaspids, the anteriorly tapering thickened denticulate area in *Coccosteus* is seen to correspond with a similar, though smaller, less clearly defined and non-denticulate area anterior to the fenestra hypophyseos in the Acanthaspids. The posterior part of this area in the latter is called by Stensiö the basal angle, against which the orbital process of the palatoquadrate articulated.

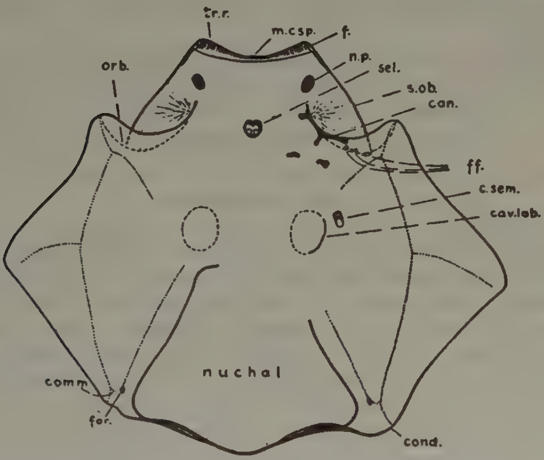
The structure of this region in *Coccosteus* and its relation to the other parts of the head do not support the idea that the median thickened region functioned as a basal angle in that genus. There is no morphological unit of the endocranial floor which may be definitely identified as the basal angle, and if, as is very probable, the median denticulate area formed part of the roof of the pharynx, it is, I think, likely that the palatoquadrates would have run forwards lateral to this area, and thus somewhere beneath the subocular shelves.

It will now be clear from what has been said concerning the anatomy of the anterior parts of the head of *Coccosteus* that the nasal tracts must have run forwards over the ethmoidal plate anteriorly to the fossa hypophyseos, in a manner resembling the condition in the Acanthaspids.

Orbital Capsules.

That part of the endocranial floor which extended beneath the eye as a subocular shelf was, as has been described, continuous anteriorly with the floor of the ethmoidal region. The dorsal surface of this shelf was upturned behind the presumed nasal pits to form the inner (mesial) wall of the orbital capsule, and in this region, i.e. anterior to the eyeball, the subocular shelf was penetrated by a number of small, elongated foramina, radiating from a point (Text-fig. 2).

The posterior and mesial walls of the orbital capsule were pierced by a number of foramina (see Text-fig. 6). There are three or four of small size in the posterior wall, which could not be further investigated without damaging the specimen, and in the mesial wall there is a relatively large ovoid foramen which, when traced inwards, is seen to be connected with a branch of the canal marked "*can.*" in Text-fig. 6, which in all probability transmitted a blood vessel. Further inwards, the foramen lost its identity in the matrix on



Text-fig. 6.—Diagrammatic reconstruction of the dorsal surface of the dermal cranial shield and endocranium of *Coccosteus osseus*, as preserved in the specimen from Buchan, Victoria. Sensory canals dotted; *can.*, canal, probably for a blood vessel; *cav. lab.*, labyrinth cavity; *comm.*, commissure between the two branches of the sensory canal system; *cond.*, position of the fossa condyli; *c.sem.*, canal, probably for the horizontal semicircular canal; *f.*, foramen leading into a canal traversing the transverse ridge; *ff.*, foramina opening into the orbit; *for.*, foramen, interpreted by Obrutschew as the foramen for the ductus endolymphaticus; *m.csp.*, median cusp; *n.p.*, nasal pit; *orb.*, orbit; *sel.*, sella turcica; *s.ob.*, subocular shelf; *tr.r.*, transverse ridge at the anterior end of the ethmoidal plate.

the mesial side of the wall of the capsule. From its position, one would suspect this foramen to mark the exit of the optic nerve to the orbit, but it may be that this nerve entered further forward still, either through a foramen in a part of the wall not preserved, or over a lower part of the wall. Stensiö found that in the Acanthaspids the optic nerve enters the orbit very far forwards, there being, in a position somewhat similar to that of the above foramen in *Coccosteus*, a kind of sinus into which canals, probably for the jugular vein and for branches of the trigeminal nerve, opened. The jugular vein then passed backwards near the lateral edge of the endocranium in a manner resembling the course of the canal "*can.*" in Text-fig. 6, and it may be that the above described foramen represents the opening to a similar sinus to that in the Acanthaspids.

With regard to the other fragments of canals, probably mainly for vessels, visible in *Coccosteus*, so little can actually be found out about their courses, due to their fragmentary preservation, that I can proceed no further with their identification.

Otic Region.

Very little detailed study of this region was attempted, because so much of the endocranial bone was seen to be badly broken, and because of the danger of damaging the specimen by further dissection. It could be determined, however, that there are, posterior to the orbits and beneath the central dermal plates, paired sacs lined with paper-thin bone (Text-fig. 6), which in all probability are the labyrinth cavities. Close to each sac are parts of two curved canals, one on the outer side running horizontally, the other on the inner and running from below upwards and mesially.

The outer canal may possibly have housed either the horizontal (lateral) semicircular canal or the jugular vein, but the function of the inner canal (whose form is not clearly visible) is not clear.

If these sacs do represent the labyrinth cavities, then the foramina in the cranial roofing bones near the fossae condylorum seem altogether too far removed from them to have been concerned with the ducti endolymphatici, as suggested by Obrutschew (1929). There seems to be no clear reason why these ducts should, in the various Euarthrodiran forms in which they are found, have opened in a more or less constant position with regard to the sensory canal grooves and the fossae condylorum, and it is significant that in *Dinichthys* they are not found at all. No trace of a canal leading from the presumed labyrinth cavities to the foramina is visible in *Coccosteus osseus*, and I think that considerable doubt may be expressed as to the correctness of Obrutschew's interpretation. Stensiö has already indicated (1934, p. 32) that in his opinion the function of these foramina cannot be stated with certainty at present.

CONCLUSION.

Certain general conclusions which can be drawn as a result of the study of the endocranium of *Coccosteus osseus* may now be summarized.

(1) The cartilaginous endocranium in *Coccosteus osseus* was lined in part with thin perichondral bone, as in *Macropetalichthys*, certain Acanthaspids, and in *Pholidosteus* and *Leiosteus*.

(2) The ossification in *Coccosteus osseus*, from the Middle Devonian, resulted in the production of a single continuous bone layer, as in the Acanthaspids and *Macropetalichthys*, from the Lower Devonian.

(3) In the shape and structure (in part) of the ethmoidal plate, the presence of subocular shelves and of a fenestra hypophyseos, and the fact that the olfactory tracts ran forward over the ethmoidal plate, the endocranium of *Coccosteus osseus* resembles that of the Acanthaspid from Podolia, described by Stensiö. Its resemblance to this form is much closer than to any other known Arthrodiran endocranium.

(4) In many points of structure, such as the details of the ventral surface of the ethmoidal plate, of the fossa hypophyseos, and of the presumed nasal pits, the endocranium is unique.

(5) It has been indicated in the text that no basal angle could be identified in *Coccosteus osseus* and, further, that some doubt may be expressed as to the correctness of the identification by Obrutschew of the situation of the dorsal ends of the ducti endolymphatici. As these observations have an important bearing on the problem of finding relatives of the Arthrodira among living fishes, I may perhaps be permitted to remark that certain of the other supposed points of similarity between the Arthrodira and the Holocephali in particular do not appear to me to be of real significance. For instance, the fact that the Arthrodiran head has, in general, a well developed rostral face, as is also the case in the Holocephali, can have little value taxonomically, because the development of the rostral face in the Holocephali is bound up with the elevation of the cranial roof, due to the presence of the ethmoidal canal and the large and high interorbital septum dorsal to the cavum cerebrale, neither of which structures is to be found in the Arthrodires. Stensiö has himself indicated that the resemblances in dentition and shape of the body are in all probability due to parallelism, and it seems that this might also apply to the presence of some kind of opercular structure in each group.

BIBLIOGRAPHY.

Allis, E. P., 1914. "The Pituitary Fossa and Trigeminofacialis chamber in Selachians," *Anat. Anz.*, xlvi, 625–637.

Chapman, F., 1916. "On the Generic Position of '*Asterolepis ornata* var. *australis*' McCoy: with Description of a New Variety," *Proc. Roy. Soc. Vict.*, xxviii (N.S.), pt. 2, 211–15.

Goodrich, E. S., 1930. *Studies on the Structure and Development of Vertebrates.* Macmillan and Co., London.

Heintz, A., 1931. "Revision of the Structure of *Coccosteus decipiens* Ag.," *Norsk Geol. Tidsskr.*, xii, 291–313.

—— 1932. "The Structure of *Dinichthys*. A Contribution to our Knowledge of the Arthrodira," *Amer. Mus. Nat. Hist.* (Bashford Dean Memorial Volume), Art. iv.

Hussakof, L., & Bryant, W. L., 1918. "Catalog of the Fossil Fishes in the Museum of the Buffalo Society of Natural Sciences," *Bul. Buffalo Soc. Nat. Sci.*, xii, 1–346.

McCoy, F., 1876. "*Asterolepis australis* (Eichwald) var. *australis* (McCoy)," *Prod. Pal. Vict.*, Dec. iv, 19, 20.

Obrutschew, D., 1929. "Über *Coccosteus trautscholdi* (Eastman)," *Trav. Mus. Geol.*, Acad. Sci., U.R.S.S., viii, 285–310.

Stensiö, E. A., 1925. "On the Head of the Macropetalichthyids, with Certain Remarks on the Head of the other Arthrodires," *Field Mus. Nat. Hist.* (Geol. Ser.), iv, 87–197.

—— 1932. "The Cephalaspids of Great Britain," *Brit. Mus.* (*Nat. Hist.*), London.

—— 1934. "On the Heads of Certain Arthrodires," *Kgl. Svenska Vet.-Akad. Hand.*, Tred. Ser., xiii, 1–79.

Stetson, H. C., 1930. "Notes on the Structure of Dinichthys and Macropetalichthys," *Bull. Mus. Comp. Zool.*, Harvard, lxxi, 19–39.

Watson, D. M. S., 1932. "On Three New Species of Fish from the Old Red Sandstone of Orkney and Shetland," *Geol. Surv. Great Britain, Summ. Prog. for 1931*, Pt. 2, 157–166.

—— 1934. "The Interpretation of Arthrodires," *Proc. Zool. Soc. Lond.*, 437–464.

Woodward, A. S., 1892. "Further Contributions to Knowledge of the Devonian Fish-fauna of Canada," Geol. Mag., 481–5.

EXPLANATION OF PLATE III.

Coccosteus osseus sp. nov., Middle Devonian, Buchan, Victoria. × $\frac{2}{3}$ approx. Showing the specimen still embedded in the matrix, the nasal pits and subocular shelves not having been dissected out. (The cost of this plate has been defrayed by the University of Melbourne from the Sweet Fund.)

The Age of the Igneous Series of Slieve Gallion, Northern Ireland.

By J. J. Hartley, Queen's University, Belfast.

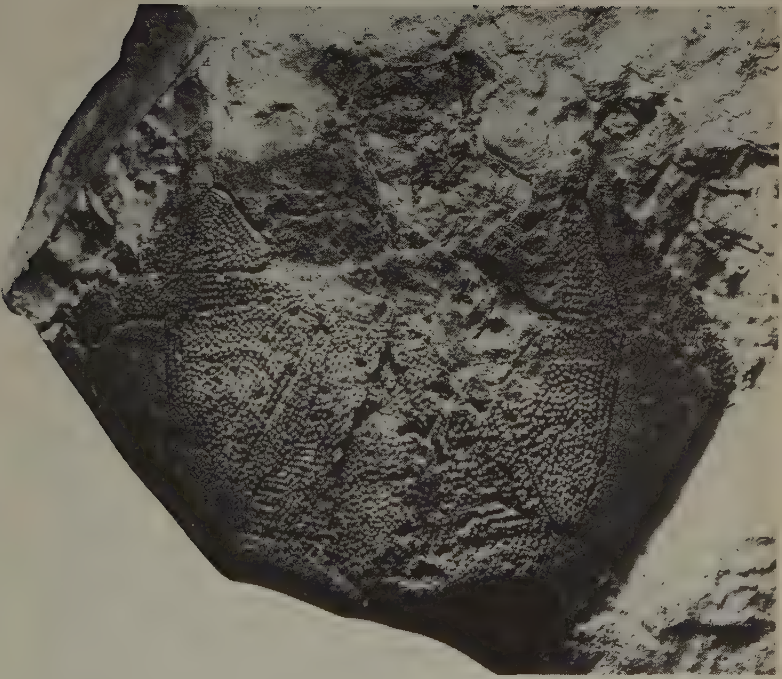
IN 1933 the present writer described[1] and mapped an igneous complex in the counties of Tyrone and Derry in Northern Ireland, to which he gave the name of the Tyrone Igneous Series.

The age of the series had at the time of publication to be left somewhat uncertain owing to lack of palaeontological evidence. It was, however, suggested[2] on lithological analogy with the

---

[1] Hartley, J. J., "The Geology of Tyrone, etc.," *Proc. Roy. Irish Acad.*, xli, 1933, ser. B., 218.

[2] *Op. cit.*, p. 278.



E. S. H. Photo.

COCCOSTEUS OSSEUS sp. nov.

Highland Border rocks of Scotland and certain basic lavas of Galway that it probably ranged from the Upper Cambrian to Arenig or Llandeilo.

During the recent excursion of the Geologists' Association to Northern Ireland last August an opportunity was taken to conduct certain members of the party to the particular locality which had appeared to be most hopeful for the discovery of fossils.

The point lies on the northern face of Slieve Gallion on the banks of a small stream, the Sruhanleanantawey Burn, at a height of 1,500 feet, and about 200 yards north of the most westerly of the three summits of the Slieve Gallion ridge.[1]

Here on the western bank of the burn black shales rest upon blue grey, somewhat gritty, tuffs, while a thick band of chert outcrops a few yards lower down the stream. Basic lavas with pillow structure overlie the shales on the higher portion of the ridge, whilst the dip of the beds in the burn is towards the south at an angle of about 50 degrees.

A careful search for fossils was made in the black shales and tuffs. No discoveries were made amongst the cleaved and pyritized shales but the experienced eye of Dr. F. Raw of Birmingham was successful in detecting a possible graptolite amongst the tuffs, which are here less intensely cleaved than the shales, though even they do not fracture easily along the bedding planes.

This fragment was subsequently examined by Dr. G. L. Elles, who identified one specimen as undoubtedly a *Dicranograptus* and most probably *Dicranograptus rectus*. She also noticed a second somewhat obscure form on the same rock fragment, which suggested a *Climacograptus*.

The beds exposed in this particular section, together with the overlying lavas and tuffs are thus on fossil evidence presumably Upper Llandeilo or Lower Caradoc in age, and definitely later than the lower or Black Shale and Chert series of the Border rocks of Aberfoyle, which yield a brachiopod fauna of Cambrian affinities, though the graptolites, *Trigonograptus* and *Cryptograptus*, are typically Arenig.[2]

The unconformity which occurs near the top of the Tyrone series on Slieve Gallion and above the fossiliferous horizon is thus apparently of purely local significance, and not equivalent to the discontinuity in Scotland.

The unconformable relations of the Ashgillian to the Tyrone Igneous Series as seen at Pomeroy, 12 miles south-west of Slieve Gallion, render Llandeilo and not Caradoc the most probable of the two alternatives mentioned above. This unconformity is a considerable one, as previously pointed out, and quite comparable, for example, to that which exists between the Bala rocks and the Borrowdale Volcanic Series of the English Lake District. Such a break between the Ashgill and Caradoc is highly improbable.

---

[1] About 700 yards south-west of the "S" of "Slieve Gallion", *op. cit.*, pl. xiii.

[2] Jehu, T. J., and Campbell, R., "Highland Border Rocks of Aberfoyle," *Trans. Roy. Soc. Ed.*, liii, 1917, 188, 194.

The writer would in conclusion like to take the opportunity of expressing his indebtedness and thanks to Dr. Elles and Dr. Raw for enabling the age of the greater part, if not the whole, of the Tyrone Igneous Series to be so much more definitely determined.

The Idea of Contrasted Differentiation.

By Arthur Holmes, University of Durham.

> "It is necessary both to disprove the older ideas and to prove the new."
> *S. R. Nockolds.*

As early as 1915, it was made clear by Bowen that, given continuous separation of crystals from the successive residual liquids of a consolidating magma which was initially basaltic in composition, the inevitable result would be a gabbroic rock in depth, a granitic one above, and "*various intermediate types in the intermediate layers*". As a necessary condition to the evolution of a magmatic residuum of granitic composition, this process of progressive crystallization differentiation involves the generation of intermediate rock-types from residual liquids of intermediate composition. Certain investigators, however, led by the authors of the Mull memoir (1924), have entirely overlooked the necessity of this condition. Faced with the association of contrasted acid and basic rocks, which is a conspicuous characteristic of many continental central complexes, they have attempted to account for the facts by introducing a modified conception of crystallization differentiation for which Nockolds[1] has recently proposed the name *contrasted differentiation*. According to this conception, the residual liquid of consolidating basaltic magma is of granitic composition and can be separated in bulk from a crystalline gabbroic phase.

In earlier contributions I have directed attention to some of the difficulties which stand in the way of accounting for the origin of granitic magmas and rocks in terms of crystallization differentiation.[2] Although these objections were, naturally, not specifically directed against the intangible idea of "contrasted differentiation", they were, in fact, concerned with the phenomena, including those of the Glen More ring-dyke of Mull,[1] in terms of which this idea has been expressed. Nevertheless, the idea is still being advocated as though these difficulties did not exist. As I believe the idea of contrasted crystallization differentiation to be without evidential foundation and to be internally unsound, it seems desirable to examine its immediate antecedents and to indicate in greater detail the elementary principles with which it is inconsistent.

---

[1] S. R. Nockolds, "The Production of Normal Rock Types by Contamination and their Bearing on Petrogenesis," Geol. Mag., LXXI, 1934, 31–9.

[2] A. Holmes, "The Problem of the Association of Acid and Basic Rocks in Central Complexes," Geol. Mag., LXVIII, 1931, 241–255; "The Origin of Igneous Rocks," Geol. Mag., LXIX, 1932, 543–558.

As far back as 1913, Bailey advanced the suggestion "that gravitational differentiation is exhibited by the contents of certain ring-dykes" in Mull; the interpretation then offered being "one of gravitational separation in a liquid emulsion" (Mull Memoir, p. 51). After consultation with Thomas and Hallimond, who pointed out that acid and basic silicate melts are miscible in all proportions, Bailey withdrew this interpretation. In its place "gravitational separation of early crystals and residual magma" was adopted.

This revised suggestion was specifically invoked to account for the "differentiation column" of the Glen More ring-dyke, in which gabbro merges upwards into granophyre by way of a transition zone of rocks showing hybrid characters (Mull Memoir, p. 324). The process envisaged is summarized as follows (p. 330): "After crystallization had proceeded for some time and had practically exhausted the magma as regards lime and magnesia, there still remained a residuum which retained its fluidity over a considerable range of temperature, so that there was, at this stage, a marked pause in the process of crystallization. . . . In such a high column of magma as these ring-dykes represent, the gravitational pressure of the early crystalline phases on the still-liquid residuum would be considerable, and would in our opinion be quite sufficient to cause an upward filtration of the still-fluid portion of the mass." It is further postulated that, as the acid residuum migrated upwards, equilibrium became so disturbed that the resulting reactions were sufficiently vigorous to evolve the hybrid rocks of the transition zone. In the actual rocks of the latter, labradorite becomes corroded, augite of columnar habit appears, and acicular hornblende is developed.

The hypothesis outlined above involves the following distinctive points :—

(*a*) the postulation of "a marked pause in the process of crystallization";

(*b*) the assumption that gravitational separation of acid residuum and gabbroic crystals is a possible process; and

(*c*) the implication that similar gravitational separation of early crystals and residual magma did not occur while the composition of the latter was passing through the intermediate stages of its evolution, but was deferred until the composition of the liquid had reached the granitic stage.

---

[1] A. Holmes and H. F. Harwood, "The Age and Composition of the Whin Sill and the related Dikes of the North of England," *Min. Mag.*, xxi, 1928, 508, 511; "The Tholeiite Dikes of the North of England," *Min. Mag.*, xxii, 1929, 49.

To each of these points there is a serious objection.

(*a*) If the hypothetical pause in crystallization were real, then the rising acid residuum could not react with the gabbroic crystals to form the hybrids of the transition zone. Consider the acid residuum at the moment when it is about to begin its upward migration. At any given depth reaction is either completed or not. If it is completed, then ascent of the acid residuum into a cooler environment cannot promote further reaction. If it is not completed, then crystallization of the reaction-products continues, at the expense of liquid and earlier crystalline material, and the phrase "pause in the process of crystallization" becomes meaningless.

(*b*) The parent magma of the rocks of the Glen More ring-dyke is presumed to have been of the tholeiite or non-porphyritic central magma-type. A characteristic representative of this magma-type is the quartz-dolerite of the Whin Sill. The latter rock has innumerable analogues in every continent, and is of special interest mainly because of the thoroughness with which it has been investigated. The occurrence of interstitial alkali felspar, quartz, and micropegmatite in the rock affords satisfactory evidence that during a late stage in the consolidation of the Whin Sill magma, the interlocking crystal-aggregate enclosed a residual liquid of acid composition. The Glen More ring-dyke, however, raises the question: Could such liquid be separated from the crystal-aggregate by simple gravitational filtration? The answer clearly depends upon the relative quantity of the acid residuum.

Microscopic examination of rocks of the Whin Sill type shows that the proportion of interstitial acid residuum is very small. On chemical evidence, which is more accurate than micrometric measurement, the average proportion in the Whin Sill itself (2,950 samples) is found by Smythe[1] to be no more than 5·5 per cent. The range is from 1·3 per cent in the Little Whin Sill of Weardale, to 10·1 per cent in the samples from Upper Tynedale. Fifteen other results obtained by Smythe fall between these extremes. These figures, based on unusually detailed and careful work, serve to confirm a theoretical calculation by Grout[2] of the proportion of granite that could be obtained from basaltic magma as a result of crystallization differentiation. Grout finds that "as a maximum one-tenth of an average basaltic magma may become granite". As he adopted an average with 1·52 per cent of potash, the result is more favourable to granite than either the Whin Sill (potash =

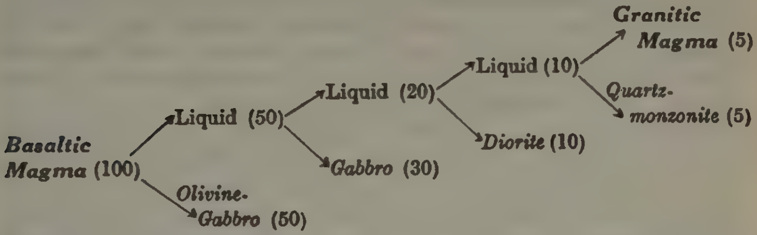
---

[1] J. A. Smythe, "A Chemical Study of the Whin Sill," *Trans. Nat. Hist. Soc. Durham, Northumberland, and Newcastle-upon-Tyne*, vii, 1930, 72.

[2] F. F. Grout, "The Use of Calculations in Petrology," *Journ. Geol.*, xxxiv, 1926, 549.

1·06) or the average tholeiite magma of the British Tertiary province (potash = 0·7 to 1·2) would be.

Grout also gives the results of another set of calculations which show that after 80 per cent of a basaltic magma has crystallized the residual magma could provide successive differentiates of *diorite* (10 per cent of the original magma), *quartz-monzonite* (5 per cent), and *granite* (5 per cent). The successive proportions of rock-types and residual liquids during progressive differentiation may be graphically summarized as follows :—



Theoretical calculations covering the general case, and the evidence of the Whin Sill in particular, show that by the time the residual liquid has reached the composition of granite it forms only 5 to 10 per cent of the whole mass. It is easily seen that this fact constitutes a fatal objection to the view that such acid liquid could collect to form a discrete body of granitic magma. Holland [1] long ago pointed out that, at the stage referred to, the crystalline framework of augite and plagioclase would be sufficiently strong to prevent collapse of the rock under any but extreme pressure. The crystals could not sink, nor could the liquid rise. Filtration, under gravity, of such a liquid-filled meshwork of closely interlocking crystals is mechanically impossible. If anyone should doubt the validity of this statement, he may refer to an admirable paper by Mead [2] on the subject of dilatancy.

Separation of the acid residuum by squeezing, due to the application of externally applied stresses, could be brought about only by intense deformation of the crystal meshwork. The necessity of this condition is clearly recognized by Eskola [3] when he refers to acid interstitial magma " which can be squeezed out if the rock is powerfully rolled out ". Eskola's reference to crystal settling serves merely to direct attention to the apparent failure of this mechanism in the Pre-Cambrian areas with which he is most familiar. There is, of course, nothing to suggest that orogenic squeezing has operated on the Glen More ring-dyke. Had it done so, the basic rock would show cataclastic structure or planar foliation. Actually, the basic rock at the exposed base of the column is a typically crystallized olivine-bearing quartz-gabbro. It exhibits no more signs of being an accumulation of sunken crystals, or of having suffered mechanical deformation, than does any other normal gabbro.

---

[1] T. H. Holland, " On Augite-diorites with Micropegmatite in Southern India," *Quart. Journ. Geol. Soc.*, liii, 1897, 410–411.

[2] W. J. Mead, " The Geological Role of Dilatancy," *Journ. Geol.*, xxxiii, 1925, 685–698.

[3] P. Eskola, " On the Origin of Granitic Magmas," *Min. Pet. Mitt.*, xlii, 1932, 469.

(*c*) Freedom of separation under gravity might be theoretically possible when the liquid formed, say 30 to 40 per cent of the mass; but at this stage in the process of consolidation the composition of the liquid would correspond, not to granite, but to gabbro-diorite or diorite. Some of the coarse pegmatitic veins of the Whin Sill (containing 12 to 25 per cent of micropegmatite) may represent this stage, but there is no proof that crystallization differentiation was the only process concerned in their genesis.[1]

To assume that the proportion of interstitial acid residuum was sufficiently high to make gravitational migration possible would be to evade the issue. The assumption could be made only if the parental magma had an intermediate composition to begin with, like that, say, of quartz-diorite, or if a residual magma of such intermediate composition migrated upwards from basic crystals of earlier formation. But neither of these suggestions has been made —so far as the Glen More ring-dyke is concerned—and indeed there is ample evidence against both. Had there been evidence in favour of either suggestion, there would have been no need for the introduction of the idea of contrasted crystallization differentiation. It is obviously a serious objection to this idea that gravitational separation of crystals and liquid did not occur in the Glen More ring-dyke while it was theoretically possible, although such separation is assumed to have occurred at a much later stage, when it had become mechanically impossible.

The inconsistencies discussed above under (*a*), (*b*), and (*c*) indicate that the hypothesis under discussion is untenable. A fourth argument, of more general character, may also be brought against the hypothesis. Were the supposed process of contrasted crystallization differentiation a real one, we might reasonably ask how it comes about that the Whin Sill and thousands of other sills and dykes of similar composition fail to show phenomena comparable with those exhibited by the Glen More ring-dyke. The very fact that acid patches, streaks, veins, etc., in these intrusions are purely local—indeed absent from vast stretches of the intrusive masses—is itself an indication that their occurrence is due to the operation of some mechanism other than crystallization differentiation (e.g. assimilation, metasomatism, gaseous transfer, introduction of an independent acid magma, or any combination of these processes). No principle which, from its very nature, implies a systematic association, will serve to explain phenomena which, in their distribution, are found to be usually rare, locally common, and commonly absent. The idea of contrasted crystallization differentiation implies so much more than the facts warrant that for this reason, too, it is unacceptable.

---

[1] S. I. Tomkeieff, "A Contribution to the Petrology of the Whin Sill," *Min. Mag.*, xxii, 1929, 100–120.

It is of some importance to realize how readily the implications of a working hypothesis may come to be accepted as demonstrated or proved: in other words, how easily opinions can be confused with facts. Reaction phenomena similar to those of the Glen More transition zone are to be seen in the "partially differentiated" quartz-dolerites of West Lothian. In reference to these, the authors of the Mull Memoir (p. 330) make the following positive statement: "It can be demonstrated that acid residual fluid, that originally existed more or less evenly distributed throughout a basic rock, has been squeezed out and segregated in certain portions of the mass." Seeking the demonstration in Falconer's description of the quartz-dolerites,[1] the statement is found that it is open to question whether the whole silica percentage of the veins and interstitial micropegmatite should be claimed as primary. Indeed, Falconer's descriptions provide more than a hint of assimilation of quartz, possibly combined with alkali metasomatism.[2] When Bailey himself comes to discuss these and related quartz-dolerites (in the Glasgow Memoir, 1925, p. 188), he gives no demonstration, but refers to recent work in Mull which, he says, "has shown that this differentiation has resulted through partial crystallization, combined with a certain amount of migration of the residual liquor". Thus the quartz-dolerite sills and dykes are used as evidence to support the case for the Glen More ring-dyke, while the latter, in its turn, is used to support the case for the quartz-dolerites. So deeply rooted has acceptance of this "evidence" become, that in 1935 the hypothesis is summarized by Richey [3] in the following words: "It is a well-known feature of quartz-dolerites and quartz gabbros that, after the gabbroic constituents have separated out, there is an appreciable pause before the acid residuum crystallizes. It was during this pause, in the case of the differentiated ring-dykes of Mull, that the granophyre mesostasis filtered upwards past the early-crystallized gabbroic minerals, which sank under gravity."

---

[1] J. D. Falconer, "The Igneous Geology of the Bathgate and Linlithgow Hills—Part II, Petrography," *Trans. Roy. Soc. Edin.*, xlv, 1906, 148.

[2] Incontrovertible evidence that quartz-dolerite, leucocratic "segregations" and granophyric veins have been generated by the action of olivine-dolerite magma on sediment incorporated within it has recently been recorded by E. D. Mountain in a paper on "Syntectic Phenomena in Karroo Dolerite at Coedmore Quarries, Durban" (*Trans. Geol. Soc. South Africa*, xxxviii, 1936, 93–112). From the lower contact of the sill a band of Table Mountain Sandstone is traced into the dolerite as a "vein" which, 13 feet from the base has become transformed into micropegmatite containing disseminated quartz grains (p. 101). In the neighbourhood of such remnants of sandstone the dolerite "varies from a normal quartz-dolerite to a granophyre" (p. 104). It is concluded that this "pale dolerite" (quartz- and/or micropegmatite-bearing) "is in all cases here produced by silicification of the dolerite-magma through incorporation of T.M.S." (p. 107).

[3] J. E. Richey, *British Regional Geology: Scotland: The Tertiary Volcanic Districts*, 1935, 67.

Since the actual evidence from the Glen More ring-dyke is itself inconsistent with the hypothesis put forward to explain the nature and distribution of its rocks, it becomes highly probable that the acid material of the transitional and granophyric zones was introduced as an independent magma. As a result of his study of the Skye complex, Harker inferred the coexistence of acid and basic magmas and suggested that the two magmas were complementary differentiates from a single parent magma. Thomas and Bailey found additional evidence in Mull confirming the validity of this inference (Mull Memoir, p. 33). They added the further suggestion that the basic differentiate was regenerated as a magma by the melting of sunken crystals. As recently as 1934, Thomas[1] repeated his conviction that "it was certain that in most of the Tertiary centres two distinct magmas were available for dyke and sill intrusion at the same time". This conclusion has been generally accepted, though as yet there is no general agreement as to the mode of origin of the two contrasted magmas. The latter problem, however, is not the issue here: the point of immediate interest is that independent magma was available.

It seems strange, therefore, that no use of this important inference was made in the attempt to interpret the Glen More ring-dyke. There is actually good field and microscopic evidence for Bailey's original suggestion of "gravitational separation in a liquid emulsion". It is worth noting that, in his discussion of a similar problem, Krokström[2] points out, without committing himself to its adoption, that the theory of liquid immiscibility affords "a fairly good explanation where the fractional crystallization seems to go short". The objection that acid and basic silicate melts are miscible opposes only the idea that a parent magma could separate into immiscible acid and basic liquid fractions, not the possibility of the temporary existence of a liquid emulsion as a passing phase in the process of mixing.

Reverting to the Glen More case, there still remains the possibility[3] —among others—that adjacent portions of coexisting acid and basic magmas may have become mechanically entangled during intrusion, under conditions of cooling and viscosity which led to the consolidation of hybrid transitional types before there was time for mutual solution to be established by inter-diffusion of the two magmas. Tomkeieff[1] offers a similar suggestion when he speaks of a "wet" magma which, "when caught up by the normal magma during injection would remain separated from it, simply because the crystallization would take place before such mixing could be accomplished." Other possibilities are by no means ruled out, but commingling of magmas would seem to be a hypothesis worth considering in the attempt to account for the peculiarities of the transition zone of the Glen More ring-dyke. It is favoured, though admittedly not proved, by the facts, (*a*) that no xenoliths of gabbro have been found in the transition zone, and (*b*) that no vertical feeders of acid material have been recorded from the gabbro in the lower part of the column.

---

[1] In discussion of S. I. Tomkeieff and C. E. Marshall, "The Mourne Dyke Swarm," *Quart. Journ. Geol. Soc.*, xci, 1934, 290.

[2] T. Krokström, "On the Ophitic Texture and the Order of Crystallization in Basaltic Magmas," *Bull. Geol. Inst., Upsala*, xxiv, 1932, 213.

[3] A. Holmes and H. F. Harwood, "The Age and Composition of the Whin Sill and the Related Dikes of the North of England," *Min. Mag.*, xxi, 1928, 511.

A general statement of the conception of contrasted crystallization differentiation has recently been given by Nockolds,[2] who writes (p. 34): "There is clear evidence that differentiation in intercrustal magma basins yields two contrasted magma types, acid and basic. These are injected successively, the basic member invariably coming first. Instead of progressive differentiation we have what we may term contrasted differentiation." But what is this "clear evidence"? The observed facts are that contrasted rock-types occur in close association and that intermediate types are often demonstrably of hybrid origin. These facts do not in themselves constitute evidence of either contrasted or any other kind of differentiation. They may be more readily accounted for by one hypothesis than another, but a generally acceptable explanation has still to be sought. Fenner[3] has repeatedly exposed the perplexing nature of such facts. In particular, drawing attention to the occurrence of alternate outpourings of typical basalt and typical rhyolite, with little or no lava of intermediate composition, he writes: "There is difficulty in bringing this phenomenon into accord with any idea of differentiation, and especially with the theory of crystal fractionation."

When the crystallization differentiation hypothesis was systematized by Bowen, it was not unreasonably expected that a wide range of rock-types would come within its scope. Now, after twenty years, although the hypothesis has often been indiscriminately applied rather than critically examined, it is becoming generally recognized that the early expectations have not been realized. By stressing the fact, as he does, that the intermediate rock-types are commonly found to be products of contamination, Nockolds brings weighty evidence against the application of the hypothesis to some of the very types which it was designed to explain. It is therefore the more remarkable that Nockolds should believe in contrasted crystallization differentiation, for which there is no evidence, in preference to progressive crystallization differentiation, for which there is at least a convincing experimental basis.

---

[1] S. I. Tomkeieff, "A Contribution to the Petrology of the Whin Sill," *Min. Mag.*, xxii, 1929, 117.

[2] S. R. Nockolds, "The Production of Normal Rock Types by Contamination and their Bearing on Petrogenesis," GEOL. MAG., LXXI, 1934, 31–9.

[3] C. N. Fenner, "The Residual Liquids of Crystallizing Magmas," *Min. Mag.*, xxii, 1931, 559.

There is no doubt as to this preference, for Nockolds's conception of " contrasted differentiation " would not only discount the evidential value of the relevant researches carried out at the Geophysical Laboratory, but would even deny to Bowen's hypothesis any credit for some, at least, of those occurrences which are consistent with its requirements. The latter point is made clear by the following statement (p. 37) : " In the magma reservoir where this contrasted differentiation occurs the acid magma may be in contact with solid basic rock for some little time before its intrusion to a higher level. Contamination will occur and both the basic and the acid material will be reciprocally modified. The basic material, being solid, will of necessity remain in place, but the contaminated acid magma (though it may contain xenocrystal and xenolithic material in the solid), is capable of intrusion at a higher level. In this way we may also have intrusions of tonalite and granodiorite which represent the original quartzo-felspathic magma contaminated, as it were, at the source."

Surely there must have been successive stages during consolidation when the residual magma itself passed through the compositions of tonalite and granodiorite. How can it be supposed that intrusion of the more voluminous residual magma of these intermediate stages should be inhibited, when no such restriction is imposed on the less voluminous acid residuum ? Why should it be assumed that the acid residuum, though originating in equilibrium with the last-formed crystalline material, should go back in its tracks and become contaminated ? The only answers to these questions which suggest themselves to me imply either (*a*) the assumption that an acid residuum could be formed during the crystallization of basaltic magma without the antecedent development of residual liquids of intermediate compositions ; or (*b*) that the acid magma originated, not by crystal fractionation of basaltic magma, but by the operation of some other process. The assumption under (*a*) is completely at variance with the results of work on silicate systems. Of the alternative processes alluded to under (*b*), the only one that is genuinely worthy of the name of contrasted differentiation is that of distillation of a gaseous phase and its consequent separation from a liquid phase.[1]

---

[1] The term *distillation* is used here for simplicity. We do not yet sufficiently understand the nature of magmatic behaviour to describe its manifestations accurately. In addition to intrinsic volatility, which does not appear to be of general importance by itself in petrogenesis, such phenomena as gaseous solution and atomic or ionic mobility are likely to be involved in processes

There is, however, nothing in Nockolds's paper to suggest that he had any process in mind other than crystallization differentiation. His summary (pp. 38–9) is clearly expressed in terms of the separation of acid liquid from basic solid. "If," he writes, "as we believe, the basic material in the magma reservoir solidifies, leaving a mobile acid residuum, then the basic intrusion represents a portion of the basic material at a time when some of it, at least, was still liquid. The acid residuum could not be intruded first for the simple reason that it was not there, and it is not until solidification of the basic material takes place that the acid residuum can be intruded as a distinct later injection." This being the view adopted, it is obviously subject to the same objections as those already discussed in connection with the official interpretation of the rocks of the Glen More ring-dyke.

Attention may here be drawn to two remarkable occurrences (Katmai and Yellowstone Park), described by Fenner,[1] affording incontrovertible evidence of complete solution of basic rock—in relatively large quantities—by rhyolite magma. This astonishing capacity of rhyolite magma is difficult, if not impossible, to reconcile with the principles of crystallization differentiation, according to which the acid residuum should be the coolest of the residual liquids. The rhyolite magma must have been intensely charged with latent energy, rapidly convertible into heat, to a degree quite incompatible with any theoretical expectations. Such energy reserves would be incredible, were there not incontestable evidence of their effects, in the sense that they could not have been deduced in advance from our existing knowledge of the thermo-chemical properties of matter. Their recognition is obviously a discovery of fundamental petrological importance. The genesis of the rhyolite magmas responsible for the phenomena described by Fenner must have involved some source of energy concerning the true nature of which we are, as yet, completely in ignorance. Essentially the same thermal problem is also raised by many less spectacular examples of contamination, metasomatism, and assimilation. Such processes have been slow to find acceptance in the minds of many petrologists because of the formidable thermal difficulties. But these difficulties

---

of differential migration. The appearance of "contrasted differentiation" may be simulated by the effects of migration of certain constituents from magmas into xenolithic material: cf. the footnote-reference to Mountain's work on page 233. Mountain points out that whereas Daly (*Igneous Rocks*, 1933, p. 434) refers to acid veins cutting Karroo dolerite in connection with the origin of acid rocks by syntexis, the same phenomena are cited by Nockolds (1934, p. 35) as emphasizing the idea of contrasted differentiation. Both authors give the same reference. The observed facts, as described by du Toit (15th *Ann. Rep. Geol. Comm. Cape of Good Hope*, 1911, pp. 120, 122, and 133; and *Trans. Geol. Soc. S. Af.*, 23, 1921, p. 16), clearly foreshadow the proof of syntexis established by Mountain.

[1] C. N. Fenner, "Some Magmatic Problems," *Journ. Wash. Acad. Sci.*, xxiv, 1934, 113–124.

limit only our understanding; they can no longer be regarded as setting a natural limit to the properties of magmas. What does remain formidable is the problem of the highly energized state of certain magmas. So far, the only differentiation process which holds out any approach towards a solution is one involving gaseous distillation from an unknown ultimate source in the hidden depths. It is inherent in the nature of such differentiation to be " contrasted "; crystallization differentiation—as a process—is inherently " progressive ".

CONCLUSION.

Nockolds ends his paper with the sentence, " Future work will no doubt show whether the idea of contrasted differentiation is more than a working hypothesis." My own conclusion, based on the following reasons, is that past research has already shown that, in so far as the idea refers to separation of residual liquid from crystal phases, it cannot be claimed as a hypothesis at all.

(*a*) The idea is inconsistent with the physico-chemical principles of crystallization differentiation established by the work of Bowen and his colleagues at the Geophysical Laboratory.

(*b*) The proportion of acid residuum in the meshwork of interlocking crystals in a nearly consolidated basic rock is so small that separation of acid magma by gravitational filtration is mechanically impossible.

(*c*) Orogenic pressure may squeeze out an interstitial acid liquid by sufficiently powerful deformation or recrystallization of the crystal network, but there appears to be no reason why such pressure should be supposed to operate on residual liquid only when it has passed beyond its intermediate stages and reached a granitic composition.

(*d*) The association of discrete bodies of acid material with basic rocks is much too variable in distribution and relative quantity to be attributable to a process which, if it occurred, would be of general application.

REVIEWS.

EINFÜHRUNG IN DIE GRUNDLAGEN DER HISTORISCHEN GEOLOGIE: I Bd., DIE AMMONITEN-, TRILOBITEN-, UND BRACHIOPODENZEIT. By R. WEDEKIND. pp. viii + 109, with 19 text-figs. and 27 pls. Stuttgart: Ferdinand Enke, 1935. Price RM. 6·50 (geh.).

THIS volume is offered to aid an elementary student in his study of historical geology and also in an endeavour to close the widening breach which the author feels to exist between the palaeontologist and the geologist, who, impatient with the morphological trend of palaeontological research, cannot keep pace with the changing nomenclature of fossils.

The author points out that a text-book of palaeontology deals primarily with the systematic relationships of fossils as members of biological groups and can thus afford little space for detailed treatment of horizon-marking species, whereas a stratigraphy book tends to list these species without drawings or descriptions. Thus a student wishing to know the age of a rock by means of fossils which he has found, must use a well organized comparative collection of fossils with assistance from specialized monographs to arrive at an accurate determination of the genus and species before his problem is solved. By giving historical accounts of some of the animal groups, employing but very few palaeontological terms and names of fossils, the author attempts to provide an easier path for the seeker.

Three groups are treated in this volume ; a second volume stated to be in preparation will deal with corals and foraminifera with particular reference to oil geology ; and a third will tell the geological history of seas and continents.

To a reader with no specialized knowledge of ammonites, the account of them is interesting and attractively even if somewhat diagrammatically illustrated ; the author has given the student a reasonable chance of deciding the probable stratigraphical position of an unnamed ammonite. The trilobites and brachiopods, however, receive much less detailed treatment, together receiving only thirty-eight pages in contrast to the fifty-seven allotted to the ammonites ; consequently surprising omissions occur, at least among trilobites, of sundry genera whose species have horizon-marking value (e.g. *Agnostus*). The reader, moreover, would be left with the impression that in the Lower Cambrian all trilobites are Mesonacidae, and that all Cambrian brachiopods have horny shells.

The aim of the book is a worthy one, for simply written books on stratigraphical palaeontology are few, but it proves a difficult task for one author to give satisfactory accounts of every group of fossils.

C. J. S.

The Stratigraphy of Palestine and its Building Stones. By G. S. Blake. Foolscap, 133 pages, 18 figures, and sketch-map. Jerusalem : The Printing and Stationery Office, 1935. Price 250 mils.

THE first part of this report has been written with the twofold purpose of establishing a standardized succession to be employed in the forthcoming geological map of Palestine, and also to give the stratigraphical positions and relationships of the various rocks of economic importance in the country. This section of the report will prove to be a very useful work of reference, especially on the Cretaceous and Tertiary strata of Palestine and Western Transjordania.

Detailed lithological descriptions of the principal sedimentary rock types are given in the section on building stones. In addition to particulars of physical properties and local occurrence, this section contains much information which is of general interest.

GETTING ACQUAINTED WITH MINERALS. By G. L. ENGLISH. pp. xi + 324, 258 illustrations. London: McGraw Hill Publishing Co., Ltd. Price 15*s*.

A BOOK for beginners, whether juvenile or adult. The introductory matter of Part I (126 pages) assumes no previous knowledge of chemistry or physics, and is written in a manner likely to arouse interest in the mineral kingdom. Part II, of similar length, is devoted to descriptive mineralogy, with many good photographic illustrations. A short section on rocks is followed by determinative tables and a pronouncing vocabulary (a very useful feature). The author's enthusiasm for his subject is evident throughout, and the intimate knowledge acquired from more than fifty years of close association with minerals is popularized without loss of accuracy. The price is unfortunately high for a wide circulation amongst British amateurs.

Notice.

INTERNATIONAL ASSOCIATION FOR QUATERNARY RESEARCH.

PROGRAMME OF THE THIRD INTERNATIONAL CONFERENCE, VIENNA, 1936.

The conference will be held in Vienna, commencing on 1st September and ending on 7th September.

After the conference, excursions will be made to the East Austrian Alps and their forelands. These excursions will start on 9th September and continue to 25th September.

Those who propose to attend the conference and excursions should write at once to the President for further details and approximate cost.

President: Prof. Dr. Albrecht Penck,
c/o Inqua,
Rasumofskygasse 23,
Vienna III, Austria.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIII.

No. VI.—JUNE, 1936.

ORIGINAL ARTICLES.

The Ordovician Rocks of New Zealand.

By W. N. Benson and R. A. Keble.

THROUGHOUT the western portion of the South Island of New Zealand there extends a series of high ranges made up very largely of unfossiliferous greywacke and argillite, with rarely limestone. Parts of these formations have been variously grouped as the Aorere and Mount Arthur series and considered to be of Ordovician age.

Fossiliferous Ordovician rocks have been discovered in but few districts. They were first recognized in the 'seventies during the gold-mining activities in the extreme north-west, and in the following decade two large collections of graptolites were obtained by Cox and Park for the Geological Survey from the vicinity of the Golden Ridge on Slaty Creek, south of the " West Wanganui Inlet " now known as West Haven. The first form to be identified was recognized by Hutton in 1878 as *Tetragraptus fruticosus*. Illustrations of a number of unnamed forms were published by Hector in 1885, but it was not until 1907 and 1908 that descriptions of fossils from this neighbourhood were published by E. de C. Clarke and Dr. Shakespear respectively, and further collections from here were described by the late Dr. T. S. Hall in 1915. About ten years ago Messrs. Grange, Macpherson, and Sylvester of the Geological Survey obtained further graptolites at various points in the Mount Arthur region, about 40 miles south-south-east of West Haven, and examination of these by the present writers in 1929 showed for the first time the presence in New Zealand of graptolites belonging to a later period than the Lower Ordovician.

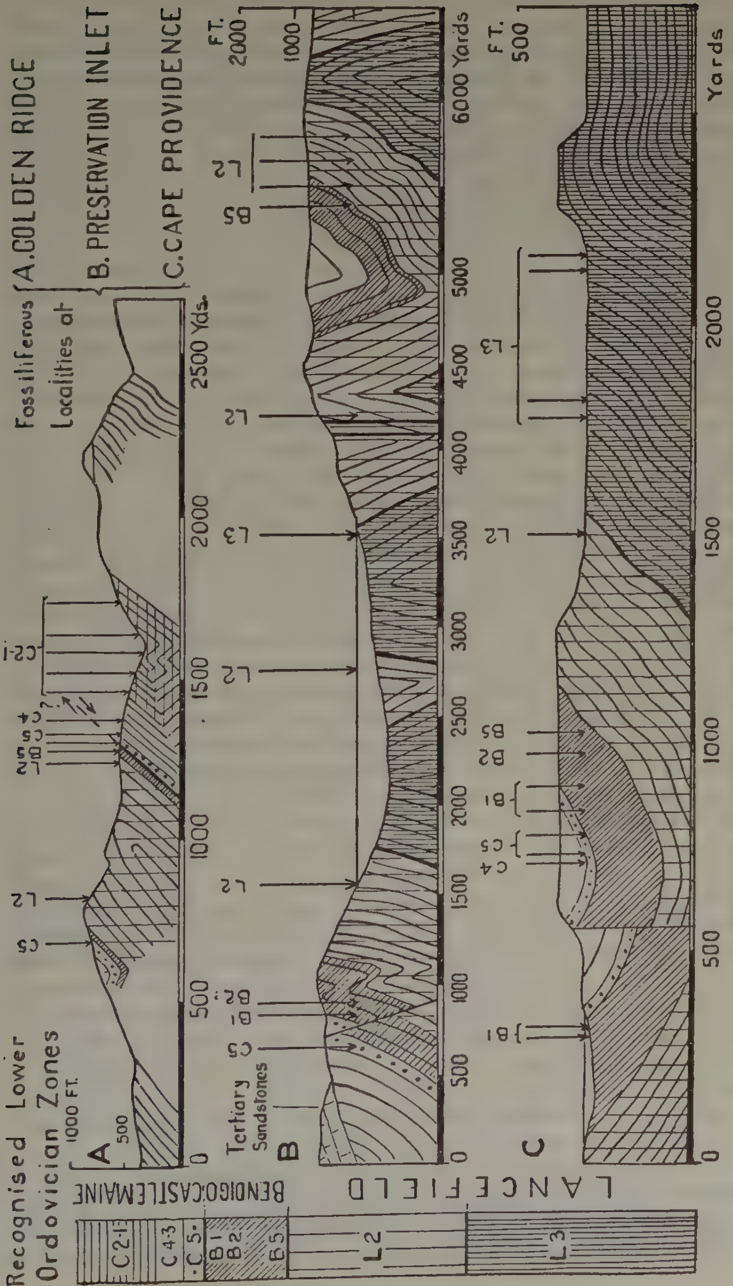
The presence of graptolites in the extreme south-west of the South Island was first noted by McKay in 1896, and a few forms obtained from there were described by Dr. T. S. Hall in 1915. Park made a further collection in 1921 which was described by Keble (1927). In 1931 Professor Bartrum and Mr. L. C. King joined with the present writers in an expedition to this south-western region (the neighbourhood of Preservation and Chalky Inlets) where a continuous series of Lower Ordovician beds was discovered, in which the sequence of eight distinct faunal assemblages was clear : seventy-eight species and varieties of graptolites, with a few sponges, brachiopods, and phyllocarids were obtained. Details of these recent studies have now appeared (Benson and Keble, 1935). Moreover, additional material was obtained from the north-western area by Ellis, King, McKee, and Service, during 1932–3, indicating the presence there of most of the Lower Ordovician zones recognized in the south-west. A detailed account of this has just been published (Benson, Keble, King, and McKee, 1936). All known occurrences of fossiliferous Ordovician rocks are, however, difficult to access, and there does not seem much prospect of further work thereon in the near future. It seems appropriate, therefore, to summarize the present knowledge concerning them, taking the occasion to add notes on the few fossils other than graptolites which have been found. It may be said that most of the determinations of the Lower Ordovician graptolites of the south-western area and of the Upper Ordovician forms have been made by Keble, while that of the collections recently acquired from the north-west and of the large Survey collections of fifty years ago has been made by Benson, by whom these notes were drafted. Grateful acknowledgement is here made to Drs. Elles and Bulman for checking and revising some of our identifications, and to Dr. Elles for the re-study of the Isaacson collection of graptolites from Slaty Creek in the north-west which had been described by Dr. Shakespear in 1908. The description of the brachiopods and phyllocarids is due to Mr. F. R. Chapman (1934) and that of the coral and trilobites to Dr. F. R. C. Reed (1927).

The sequence of graptolite-assemblages in New Zealand has proved to be so closely similar to that in Victoria that it is appropriate to apply the Victorian stratigraphical classification to the New Zealand rocks ; that suggested formerly by us (Keble and Benson, 1929), based on New Zealand place-names, seems now to be unnecessary.[1] The position of the several subdivisions recognized in the Lower Ordovician rocks is made clear in the geological sections herewith (p. 243), but the sequence of the later Ordovician rocks can as yet be inferred on palaeontological grounds only.

The lowest fossiliferous beds at present known in New Zealand occur in the south-west on Cape Providence and in Preservation Inlet. They consist of at least 1,500 feet of greywacke, argillite, and slate, the latter characterized by the abundance of *Tetragraptus decipiens* T. S. Hall. With these there occur *Dictyonema macgillivrayi* T. S. Hall (a form reaching 14 inches in diameter),

---

[1] Recent summaries of the Ordovician sequence in Victoria have been given by Elles (1932), Harris and Keble (1932), Thomas and Keble (1933), Harris (1935), and Thomas (1935).



Sections through Ordovician Rocks in New Zealand.

Clonograptus tenellus Linnarsson, *C. tenellus* var. *callavei* (Lapw.), *C. magnificus* Pritchard, *Bryograptus antiquus* (T. S. Hall), *B. clarkei* T. S. Hall, *B. hunnebergensis* Moberg, *B. victoriae* T. S. Hall, *Didymograptus taylori* T. S. Hall, and *Triograptus otagoensis* Benson and Keble. The last species belongs to a three-branched genus hitherto known only in the neighbourhood of Oslo, Norway. The brief appearance of this short-lived and unstable form at the time of the introduction of the primitive Didymograptids is an interesting feature. This assemblage is directly comparable with that in the Middle Lancefield or L. 3 beds of the Victorian sequence.

There follows in the southern area about a thousand feet of beds of a similar range of lithological characters, in which the many branched forms (Bryograptids and Clonograptids) become very abundant. Analogous strata form the lowest known members of the sequence in the Slaty Creek region in the north-west. The dominant forms in these beds are *B. hunnebergensis*, *C. tenellus* var. *kingi* B. and K., and *T. decipiens*. Associated with these are *B. antiquus*, and var. *inusitatus* B. and K., *B. clarkei*, *B.* cf. *divergens* Elles, and var. *subsimus* B. and K., *B. simplex* Tqt., *B. victoriae*, *C. flexilis* (J. Hall), *C. rigidus* (J. Hall), *Dichograptus octobrachiatus* (J. Hall), *T. decipiens* var. *bipatens* H. and K., *T.* cf. *postlethwaithei* Elles, *T. quadribrachiatus* (J. Hall), *Didymograptus eocaduceus* Harris, *D. pritchardi* T. S. Hall, and *D. taylori*, together with *Dictyonema macgillivrayi*, all in small amount. This assemblage is comparable with that occurring in the higher or L. 2 zone of the Victorian Lancefield series. The beds containing it are followed directly by basal Bendigonian beds, both in the northern and southern portions of the South Island of New Zealand, the thickness of the strata wherein the L. 1 assemblage (characterized by *Tetragraptus approximatus* Nich., unaccompanied by *Tetragraptus fruticosus* (J. Hall)) might occur being very small.

The basal zone B. 5 of the Bendigonian series is characterized by the association of *T. approximatus* with the four-branched form of *T. fruticosus*, in an assemblage dominated by *T. quadribrachiatus*, which has here its maximum development. A form resembling *T. postlethwaitei* is abundant, *T. acclinans* Keble with *T. decipiens* and var. *bipatens* are common, and there occur also in smaller numbers *B. clarkei*, *B.* cf. *lapworthi* Rued., *B.* cf. *simplex*, *C. tenellus*, *Tetragraptus chapmani* K. and H., *T. pendens* Elles, *Didymograptus* cf. *aureus* T. S. H., *D. bartrumi* B. and K., *D. latus* T. S. H., *D. simulans* Elles, and a few small early members of the *D. extensus-nitidus* series.

According to Dr. Elles (1933) the Lancefield beds as here described correspond with the *Dichograptus* zone of the British sequence, but as the highest portion of that zone is characterized by a wealth of horizontal Tetragraptids, the special feature of our B. 5 beds, it seems appropriate to consider that they also are to be included in the equivalents of the *Dichograptus* zone. The B. 4 beds of

Victoria into which the reclined Tetragratids enter, and in which the extensiform Didymograptids become much more abundant would then appear to be the equivalent of the basal portion of the *D. extensus* zone of Britain. Neither B. 4 beds nor those containing the fauna of the B. 3 beds of Victoria have yet been recognized *in situ* in New Zealand, though a pebble with a few forms suggesting a B. 4 age was obtained on Cape Providence. Beds comparable with the Victorian B. 2 are known in the south-west and are characterized by the abundance of the three-branched form of *T. fruticosus*, the reclined forms *T. serra* (Brongn.), and *T. similis* (J. Hall) = *T. bigsbyi* J. Hall, and members of the *D. extensus-nitidus* series, with which are associated *Goniograptus macer* T. S. H., *G. thureaui* McCoy, *Sigmagraptus laxus* (T. S. H.), *Tetragraptus harti* T. S. H., *T. pendens*, *T. quadribrachiatus*, *Didymograptus artus* E. and W., *D. similis* (J. Hall), *Phyllograptus angustifolius* J. Hall, *P. anna* J. Hall, *P. ilicifolius* J. Hall, and rarely obscure biserial forms resembling *Cryptograptus* and *Diplograptus*.

The succeeding B. 1 strata are rich in fossils. The dominant forms are still *T. fruticosus*, the reclined Tetragraptids, Phyllograptids, and extensiform Didymograptids. With these are associated in smaller numbers *Clonograptus abnormis* J. Hall, *Goniograptus crinitus* T. S. H., *G. macer*, *S. laxus*, *T. amii* E. and W., *T. harti*, *T. pygmaeus* Rued., *T. quadribrachiatus*, *T. taraxacum* Rued., *T. whitelawi* T. S. H., *Didymograptus harrisi* B. and K., *D. nicholsoni* var. *aotea* B. and K., *D. similis*, and the pendent forms *D. artus* E. and W., and *D. protobifidus* Elles. The presence of the last two species, which occur in very small numbers only, is the feature which distinguishes this assemblage from the preceding one. This is precisely the association of forms in the B. 1 beds of Victoria, and if it be held to characterize the highest zone in the Bendigonian (concerning which a comment is made below), then that series is about 550 feet thick in the south-west of New Zealand, and apparently less than a hundred feet thick in the northern area, where, however, the rocks are disturbed by strike-faulting.

Above the B. 1 bed the faunal assemblage changes very rapidly. Didymograptids now dominate, and *D. protobifidus* is by far the most abundant species, and is associated with extensiform transients which occasionally reach the *D. patulus* (J. Hall) or even the *D. suecicus* Tullbg. stage of development. The dependent Tetragraptids almost disappear and reclined Tetragraptids, though common, are quite subordinate; *T. reclinatus* Elles now occurs sparingly among them, *T. amii*, *T. harti*, *T. pendens*, *T. quadribrachiatus* are present in small numbers. The Phyllograptids are common, and the large form *P. ilicifolius* var. *grandis* E. and W. is occasionally present. *Dichograptus octobrachiatus*, *Didymograptus adamantinus* T. S. H., *D. affinis* Nich., *D. artus*, *D. bidens* Keble, *D. gracilis* Tqt., *D. mundus* T. S. H., *D. procumbens* T. S. H., *D. simulans* Elles, and *Strophograptus trichomanes* Rued. are rather rare. A form resembling

Diplograptus inutilis J. Hall occurs very rarely. The most noteworthy addition to the fauna is *Isograptus caduceus* (Salter *pars*) = *I. gibberulus* (Nich.) in its small early form, the var. *primula* of Harris. It occurs sparsely in the lower portion of the beds containing this fauna, but is more abundant in the upper. This faunal assemblage is that of the basal Castlemainian or C. 5 zone in Victoria.

It may here be remarked that if the mere entry of a new species such as *D. protobifidus* into a fauna should be taken as indicating the commencement of a new stratigraphical division, then the boundary between the Bendigonian and Castlemainian might be placed at the base of B. 1 in which it first appears, as Dr. Hall (1894) foreshadowed and Dr. Elles (1932) has done. The Victorian records which she utilized, have, however, seldom stressed the far greater abundance of *D. protobifidus* in the C. 5 beds. If the entry of a characteristic species *in abundance* with a consequent marked change in the concentration of the faunal groups should be the significant factor, as Dr. Elles (1925, 1933) has emphasized, then the base of the Castlemainian may still be that of the C. 5 beds. This is also the point of entry of definite *Isograptids* and of a marked decline in the Tetragraptids. The relative concentrations of the several faunal groups are tabulated on page 249. In a general way the C. 5, B. 1, and possibly the B. 2 beds are comparable with the *D. nitidus* sub-zone of the British *D. extensus* zone. The C. 5 beds are known at both ends of the South Island of New Zealand, and are apparently not much more than a hundred feet thick.

There follows above them in both regions beds which correspond with the less well known Middle Castlemainian beds of Victoria, the C. 4 and perhaps also C. 3 beds. The dominant forms in these are extensiform Didymograptids (which occur in all transient stages up to that of a late development of *D. suecicus*), varieties of *I. caduceus* passing through the *primula* and *lunata* stages and almost reaching that marked by the var. *victoriae* of Harris, and the same Phyllograptids as before. Horizontal and reclined Tetragraptids are present in a subordinate role, and *T. woodi* Rued. has entered the fauna. *D. protobifidus* has disappeared, and in its place there is a small development of *D. dependulus* H. and K. which is perhaps a descendant therefrom. A form resembling *Diplograptus longicaudatus* Rued. occurs in this zone. The thickness of this zone is not directly determinable, but unless its apparent thickness be greatly lessened by strike faulting, it can hardly be more than a hundred feet.

The highest Castlemainian beds corresponding to the zones C. 2 and perhaps C. 1 of the Victorian sequence occur in appropriate position in the north-west where they are several hundred feet thick, but are as yet represented by pebbles only in the south-west. The fauna is dominated by large forms of *Isograptus caduceus*, reaching the stage of var. *victoriae* and var. *maxima* of Harris, while *I. hastatus* Harris is also present. The many-branched forms are represented by *Bryograptus* cf. *lapworthi*, some indeterminate Clonograptids, *Goniograptus crinitus*, *G. laxus*, *G.* cf. *perflexilis* Rued., *Dichograptus octobrachiatus* and *Loganograptus logani* (J. Hall), which last appears for the first time at this horizon in New Zealand so far as is yet known, though in Victoria, while this is its chief horizon, it has been noted very sparsely near the top of the Lancefieldian. Except for the absence of *T. woodi*, the Tetragraptids, Phyllograptids, and extensiform Didymograptids are the same as those of the C. 4 beds with the addition of *D. mundus* and *D. simulans*. A noteworthy feature is the presence of *Cryptograptus hopkinsoni* Nich., and rarely of a form resembling *Diplograptus inutilis*. It is clear that the fauna of these Upper Castlemainian beds, and to a less marked degree that of the Middle Castlemainian also, corresponds with that of the highest or *I. gibberulus* sub-zone of the British *D. extensus* zone and that, here as in the case of equivalents of the *D. nitidus* sub-zone, the spreading of the fauna both in Australia and in New Zealand permits a closer subdivision of strata than is possible in Britain, as Dr. Elles has indicated (1933). It should be added that this close correlation of antipodean strata, which differs from that previously suggested by Harris and Keble (1932), has been made possible by Dr. Elles's recent study of the Skiddaw succession.

The highest Lower Ordovician beds of Victoria, the Darriwil Series, approximately coeval with the *D. hirundo*, *D. bifidus*, and *D. murchisoni* zones of Britain, are as yet unknown in New Zealand, unless they be represented in the north-west by beds in the Leslie River Valley, near Mount Arthur, which have yielded a form compared doubtfully with *Didymograptus euodus* Lapw.

The beds comparable with the Llandeilian of Britain or the Gisbornian (early Upper Ordovician according to Victorian usage), all occur in the Mount Arthur region, and have so far been found only at isolated localities, so that their relative ages have been determined on palaeontological evidence only. The oldest or Cobb bed was at first considered by us to be referable to the top of the Darriwillian, but recent Victorian work (Thomas and Keble, 1933), show that it is better considered to be basal Gisbornian. It contains over thirty species, and has been recognized in two places. It is characterized by the abundance of *Diplograptus spiculatus* K. and B., and also of *D.* (*Glyptograptus*) *euglyphus* var. *sepositus* K. and B. with *Glossograptus hincksi* Hopk. and *Retiograptus speciosus* Harris. Associated with these, though less abundant, are *Didymograptus euodus*, *D.* cf. *sagitticaulis* Gurley, and var. *cobbensis* K. and B., *D.* cf. *superstes* Lapw., *I. caduceus* var. *spinifer* K. and B., *I. ovatus* T. S. H., *Tetragraptus* (?) *insuetus* K. and B., *T. tabidus* K. and B., *Azygograptus prolixus* K. and B., *Glossograptus* cf. *herrmanni* T. S. H., *G. acanthus* E. and W., *G. villosus* K. and B., *Retiograptus* cf. *geinitzianus* J. Hall, *R. latus* K. and B., *Lasiograptus* sp., *Pterograptus elegans* Holm, *Syndyograptus* ? *artus* K. and B., *Leptograptus flaccidus*

J. Hall var. *angustus* K. and H., *Cryptograptus tricornis* Carr., *Climacograptus missilis* K. and H., *C.* cf. *antiquus* Lapw., *D.* (*Orthograptus*) *quadrimucronatus* J. Hall, *D.* (*G.*) *euglyphus* Lapw. and var. *coitus* K. and B., *D.* (*Amplexograptus*) *perexcavatus* Lapw. and *D.* (*G.*) *teretiusculus* (His.). The forms are not well preserved, and the identifications are doubtful in some cases. The assemblage seems, however, to correspond with that of the lowest portion of the Gisbornian rocks of Victoria, and may be about coeval with that of the *G. teretiusculus* zone of Britain.

The succeeding zone is probably that displayed at the Loadstone Peak and Mount Peel in the Mount Arthur region. This is less rich than the last from which it differs in the entry of Dicellograptids, and the disappearance of most of the Didymograptids and Glossograptids. The following are the forms so far recognized: *D. spiculatus*, *D. euglyphus* var. *sepositus*, *D.* (*O.*) *quadrimucronatus*, *D. semotus* K. and B., *D.* cf. (*O.*) *truncatus* Lapw., *Climacograptus missilis*, *Cryptograptus tricornis*, *Dicellograptus* cf. *affinis* T. S. H., *D.* cf. *divaricatus* J. Hall, *D.* cf. *elegans* Carr, *D.* cf. *moffatensis* Carr. and a few indeterminate Glossograptids. The assemblage appears to be about coeval with the middle portion of the Gisbornian series, and perhaps also with the *Nemagraptus gracilis* zone of Britain.

The much smaller assemblage on the Flora Track (again in the Mount Arthur region) differs from the last in the presence of *Climacograptus bicornis* J. Hall, and *Dicranograptus* sp. A still smaller collection from the head of the Leslie River, 8 miles to the west, yielded *Dicranograptus* cf. *rectus* Hopk. as the only form for which a specific name could be suggested. These are possibly coeval with the upper part of the Gisbornian, and with the British *Climacograptus peltifer* zone. They are the youngest graptolite-bearing rocks yet known in New Zealand.

More than 3,000 specimens of New Zealand graptolites have now been determined, and a census of 2,816[1] individuals has been analysed. Though most of the stratigraphical divisions have as yet been recognized in so few localities that we cannot assume the average abundance of the several groups of graptolites recorded in any divisions is uninfluenced by local peculiarities, the averages may, however, suffice to give a broadly qualitative indication of their changing concentration as the fauna evolved throughout the period represented by the strata present. These averages are given in the following table, in which the relative abundance of the many-branched forms and of the horizontal Didymograptids may perhaps have been rather underestimated for the zones which they dominate. The sign " x " indicates that the group of forms denoted makes less than one per cent of the fauna of the zone. The figures for the characteristic groups in each zone are shown in heavy type.

---

[1] These do not include the mixed C. 5 and C. 2–1 specimens comprising the Isaacson collection now in the British and Sedgwick Museums.

DISTRIBUTION OF GRAPTOLITES IN NEW ZEALAND ORDOVICIAN ROCKS.

ries . .	Lancefield			Bendigo				Castlemaine				Drl	Gisborne		
nes . .	L. 3	L. 2	L. 1	B. 5	B. 4–3	B. 2	B. 1	C. 5 low	C. 5 high	C. 4–3	C. 2–1		G*c*	G*b*	G*a*
tal Specimens	91	253		219		103	268	1190	126	73	140		250	79	24
ndroidea .	%	%	Not known in New Zealand.	%	Not yet known *in situ* in New Zealand.	%	%	%	%	%	%	Darriwil Series not known in New Zealand.	%	%	%
ctyonema .	5	1		—		—	—	—	—	—	—		—	—	—
aptoloidea .															
ny-branched forms.															
Dependent .	35	52		6		—	2	x	—	—	x		—	—	—
Horizontal .	5	16		1		8	2	2	5	4	7		—	—	—
tragraptids.															
Horizontal .	35	20		61		1	10	3	7	8	4		1	—	—
Dependent .	—	1		25		28	29	x	2	—	—		—	—	—
Reclined .	—	—		—		19	18	6	19	14	4		1	—	—
yllograptids .	—	—		—		19	21	14	10	14	6		—	—	—
iograptids .	15	—		—		—	—	—	—	—	—		—	—	—
dymograptids.															
Horizontal .	5	8		7		23	13	15	12	18	18		10	—	4
Reclined .	—	2		—		—	—	—	—	—	—		—	—	—
Declined .	—	—		—		—	2	x	4	—	x		—	—	—
Dependent .	—	—		—		—	2	55	17	4	—		—	—	—
graptids .	—	—		—		?	?	4	24	34	56		3	—	—
ygograptids .	—	—		—		—	—	—	—	—	—		x	—	—
erograptids .	—	—		—		—	—	—	—	—	—		1	—	—
yptograptids	—	—		—		?	—	—	—	—	6		4	2	9
gonograptids	—	—		—		—	—	—	—	—	—		?	—	—
plograptids .	—	—		—		2	1	—	—	3	?		38	54	44
ssograptids .	—	—		—		—	—	—	—	—	—		18	2	4
tiograptids .	—	—		—		—	—	—	—	—	—		9	—	—
siograptids .	—	—		—		—	—	—	—	—	—		x	—	4
macograptids	—	—		—		—	—	—	—	?	—		12	9	9
ptograptids .	—	—		—		—	—	—	—	—			2	—	—
ellograptids	—	—		—		—	—	—	—	—	—		—	33	17
ranograptids	—	—		—		—	—	—	—	—	—		—	—	9
ophograptids	—	—		—		—	—	x	x	—	—		—	—	—
prox. coeval tish Zones .	*Dichograptus* 3				4*ab*			*D. extensus* 4*c*			4*d*	5–7	8	9	10

Ordovician fossils other than graptolites are rare. The limestone in the north-west contains traces of corals and of indeterminate crinoid stems. McKay found these in 1879 at the junction of the Dart and Wangapeka Rivers, 12 miles south of Mount Arthur, and near the graptolitic slates by the Lodestone and Flora tracks. The coral obtained by Park (1889) further northwards from the Takaka River, 8 miles from its mouth, was compared by Dr. F. R. C. Reed (1927) to *Palaeopora* (*Heliolites*) *inordinata* Lonsd., a form occurring in the Bala limestone of Pembrokeshire, the Silurian limestone of Ireland, and the Helderbergian (?) of New Brunswick.

Sponges resembling *Protospongia oblonga* T. S. Hall, and *Megastylia* (?) have been recognized in the Lower Ordovician rocks of the south-western area, wherein Chapman (1935) has also recognized the occurrence of *Leptobolus novaeozealandica* Chapm. and *Obolus* (?), among some small, obscure brachiopods. The same authority (Chapman, 1935*a*) has determined the phyllocarids which range in the south-western region from the Middle Lancefieldian into the Lower Castlemainian. They are as follows: *Caryocaris marri* Hicks, *C. minima* Chapm., *C. wrighti* Salter, *Hymenocaris bensoni* Chapm., *H. lepadoides* Chapm., *Lingulocaris* cf. *acuta* (Bulman), *Rhinopterocaris bulmani* Chapm., *R. maccoyi* (Eth. fil.), and *R. maccoyi* var. *tumida* Chapm. Several of these have been found in the Lower Castlemainian rocks near Slaty Creek in the north-western area (Benson and others, 1936), and there are indistinct traces of Phyllocarids rarely visible in the Cobb (Lower Gisbornian) beds. Dr. F. R. C. Reed (1927) has described as *Ogygites collingwoodensis* Reed a trilobite which Kobayashi (1934) states is very close to his new Middle Ordovician genus *Basiliella*. This form occurred in a boulder found a few miles east of the Slaty Creek area. The Upper Ordovician form *Dionide hectori* Reed was obtained from near the head of the Wangapeka River, some twenty miles south of Mount Arthur. With the mention of these species our citation of the known Ordovician fauna of New Zealand is completed.

The relationship of the Ordovician sediments to the neighbouring schistose formations has been variously interpreted. In the north-west some authorities have considered that there was a transition traceable between these two formations, while others have held they were sharply separable and of different ages. In neither case was the opinion based on detailed studies. In the central portion of the western slopes of the South Island, Morgan and Bartrum have described the passage of unfossiliferous but presumably Ordovician sediments into crystalline schists. In the south-western area there is the clearest evidence traced in petrographical detail of the passage of fossiliferous Ordovician slates and greywackes into a highly metamorphosed series of mica-schists, the distinction between the thermally metamorphosed hornfelses and the dynamo-thermal crystalline schists being recognizable (Benson and Bartrum, 1935). The probability thus demonstrated that highly altered schists here are derived from Ordovician sediments has left no valid reason for assuming the pre-Palaeozoic age of any known formations in this part of New Zealand, or perhaps in any part of the Dominion.

LITERATURE CITED.

BENSON, W. N., and BARTRUM, J. A. 1935. "The Geology of the Region about Preservation and Chalky Inlets, Southern Fiordland, N.Z. Part 3: Petrology," *Trans. Roy. Soc. N.Z.*, 65, 108–152.

—— and KEBLE, R. A. 1935. Ibid, Part 4: "Stratigraphy and Palaeontology of the Fossiliferous Ordovician Rocks," *ibid.*, 244–294.

BENSON, W. N., and KEBLE, R. A. 1936. (With King, L. C., and McKee, J. T.) "The Ordovician Graptolites of North-west Nelson, N.Z.," *ibid.*, 357–382.

CHAPMAN, F. 1934. "On some Brachiopods from the Ordovician of Preservation Inlet, New Zealand," *Trans. Roy. Soc. N.Z.*, 64, 115–16.

—— 1934*a*. "On some Phyllocarids from the Ordovician of Preservation Inlet, New Zealand," *ibid.*, 105–114.

CLARKE, E. DE C. 1907. (In Bell, J. M., and others.) "The Geology of the Parapara Subdivision," *Bull. Geol. Surv. N.Z.*, No. 3, 35–37.

ELLES, G. L. 1925. "The Characteristic Assemblages of the Graptolite Zones of the British Isles," GEOL. MAG., 62, 337–347.

—— 1932. (In David, Sir T. W. E.) *Explanatory notes to accompany a new Geological Map of the Commonwealth of Australia*, Sydney, p. 40.

—— 1933. "Lower Ordovician Graptolite Faunas with special reference to the Skiddaw Slate," *Geol. Surv. Gt. Brit., Summary of Progress*, 1932, pt. 2, 94–198.

HALL, T. S. 1894. "Notes on the Distribution of Graptolites in the Rocks of Castlemaine," *Aust. Assoc. Adv. Science*, 4, 374–6.

—— 1915. "On the Occurrence of Lower Ordovician Graptolites in Western Otago," *Trans. N.Z. Inst.*, 47, 410–11.

—— 1915*a*. "The Golden Ridge Graptolites," *ibid.*, 411–12.

HARRIS, W. J. 1935. "The Graptolite Succession of Bendigo East with suggested Zoning," *Proc. Roy. Soc. Vict.*, 47, 314–337.

—— and KEBLE, R. A. 1932. "Victorian Graptolite Zones with Correlations and Descriptions of New Species," *Proc. Roy. Soc. Vict.*, 44, 25–48.

KEBLE, R. A. 1927. Graptolites from Cape Providence, Chalky Inlet, Southland," *Trans. N.Z. Inst.*, 58, 157–9.

—— and BENSON, W. N. 1929. "Ordovician Graptolites of North-West Nelson, N.Z.," *ibid.*, 59, 840–863.

KOBAYASHI, T. 1934. "The Cambro-Ordovician Formations and Faunas of Southern Chosen : Part I," *Journ. Fac. Sci. Imp. Univ. Tokyo*, 3, pt. 8, 470, 486.

REED, F. R. C. 1927. "New Trilobites from the Ordovician Beds of New Zealand," *Trans. N.Z. Inst.*, 57, 310–14.

SHAKESPEAR, E. M. R. 1908. "On Some New Zealand Graptolites," GEOL. MAG., 145–8.

THOMAS, D. E. 1935. "Cambrian and Ordovician" (in *Outline of the Physiography and Geology of Victoria*). Handbook for Victoria, Melbourne meeting, Aust. and N.Z. Assoc. Adv. Science, pp. 96–105.

—— and KEBLE, R. A. 1933. "The Ordovician and Silurian of the Bulla-Sunbury Area, and discussion of the Sequence of the Melbourne Area," *Proc. Roy. Soc. Vict.*, 45, 49–56.

The Basal Complex Question in Jamaica.

By C. T. TRECHMANN.

INTRODUCTION.

A QUESTION of considerable importance in the geology of the Greater Antilles has lately re-arisen and concerns the following alternatives :—

1. Whether in Jamaica an old granitic and metamorphic pre-Mesozoic (possibly pre-Palaeozoic) basement exists and can be recognized in the present structure of the island.

2. Whether the granite, serpentine, marble, and other igneous and metamorphosed rocks of the island are the result of Cretaceous and Tertiary intrusion and metamorphism.

Regarding the granite mass of Jamaica, Sawkins wrote in 1863 [1]:—"This formation first appears in the parish of Port Royal, piercing through the Carbonaceous Series; then west of the Hope River in the parish of St. Andrew, between the White Limestone and conglomerates. It is consequently of Tertiary age. It sinks below the White Limestone at Stony Hill, rises again through the same to the N.W., and trends off into the parish of Metcalfe, where I found the copper associated with the granite series."

In some instances however Sawkins [2] seems to have had moments of doubt during the survey and speaking of the syenite in the parish of Metcalfe he says this and other groups "are evidently of older formation than the stratified series".

A. Lennox,[3] in a paper printed only in abstract in 1864, states that "the White Limestone everywhere at its junction with the igneous rock in St. Catherine is highly altered", and "the granite of St. Thomas-in-the-Vale is certainly posterior in date to the deposition of the White Limestone formation".

R. T. Hill [4] holds the view that there are no rocks in Jamaica older than Cretaceous and discussing the hornblende-diorites, porphyries and granitoid rocks says:—"no evidence exists that they were ever protruded at the surface; we believe they represent the various phenomena of a great laccolith which in Tertiary (mid-Oligocene) times were protruded upward into the existing formations of the Jamaican sequence."

I have all along held a view agreeing in general with that of Sawkins, Hill, and Lennox and was surprised when Dr. C. A. Matley about ten years ago told me when we were in Jamaica that he had come to the conclusion that the granite or granodiorite is of pre-Cretaceous age and forms part of an old basal complex to which also the serpentines, the Serge Island marble, hornblende-schists etc. belong. Since then he has published his views [5] in detail in a paper with a petrological appendix by F. Higham, entitled "The Basal Complex of Jamaica with special reference to the Kingston district".

G. M. Stockley [6] speaks of the "Granite and Serpentine of the Fundamental Floor" as of pre-late Cretaceous age and underlying unconformably the Blue Mountain series. Further on (p. 32) he writes: "According to Hill the Tertiary limestones were supposed to have been intruded by the Granite Bathylith. There is no field or microscopical evidence to bear out such an assertion. The contact is an unconformable junction." And later on "The Serpentine in Jamaica may be the same age as the Cuban serpentine, which is said to be of Jurassic age". On page 34 Stockley gives details of progressive metamorphism across sections of 4–5 miles of country in the Blue Mountain area at Green River, Hagley Gap etc., with petrological determinations of hornfels and other rocks. Stockley however excludes these schistose rocks and marbles from the fundamental floor, considering that they are of later age, and are the metamorphic derivatives of the Blue Mountain series.

---

[1] J. G. Sawkins, *Quart. Journ. Geol. Soc.*, xix, 1863, p. 35.

[2] "Report of the Geology of Jamaica," *Mem. Geol. Survey*, London, 1869, p. 113.

[3] *The Geologist*, 1864, pp. 226–7.

[4] "The Geology and Physical Geography of Jamaica," *Bull. Mus. Comp. Zool., Harvard*, xxxiv, 1899, pp. 1–226.

[5] *Quart. Journ. Geol. Soc.*, lxxxv, 1929, pp. 440–492.

[6] "Final report of the Government Geological Department," Supplement to the *Jamaica Gazette*, 27th March, 1925, pp. 23–35.

For some years I have had under observation various sections in Jamaica bearing on this question and recently have looked them over again, including most of those that Matley refers to in his paper, so my observations and conclusions may be of some interest to geologists.

GENERAL STRUCTURE.

Jamaica is 144 miles long from east to west and is flanked by some great ocean depths, for instance 2,800 fathoms between it and Cuba. Cretaceous fossils indicating high Senonian, Maestrichtian, and possibly Danian horizons occur from 7,000 feet altitude near Blue Mountain Peak to deep down in the interior valleys. This year I collected an ammonite in what are probably the lowest known fossiliferous shales, some 800 feet below a *Barrettia* limestone in the St. Ann's Great River Valley near the north coast. Dr. L. F. Spath has kindly determined it as "*Sonneratia*" *paillettei* d'Orb (in Grossouvre, 1893, p. 149, pl. xxxvii, fig. 2) = *Nowakites* aff. *paillettei*. The horizon suggested is Senonian (Upper Coniacien or Lower Santonian).

Beds up to the Carbonaceous Shale (Richmond or Mount Hybla beds), a Flysch-like development of the lower Eocene, have been involved in the tectonics of the Blue Mountain complex and some of these, on the evidence of *Velates* etc. may partly correspond to the Yellow Limestone of lower levels.

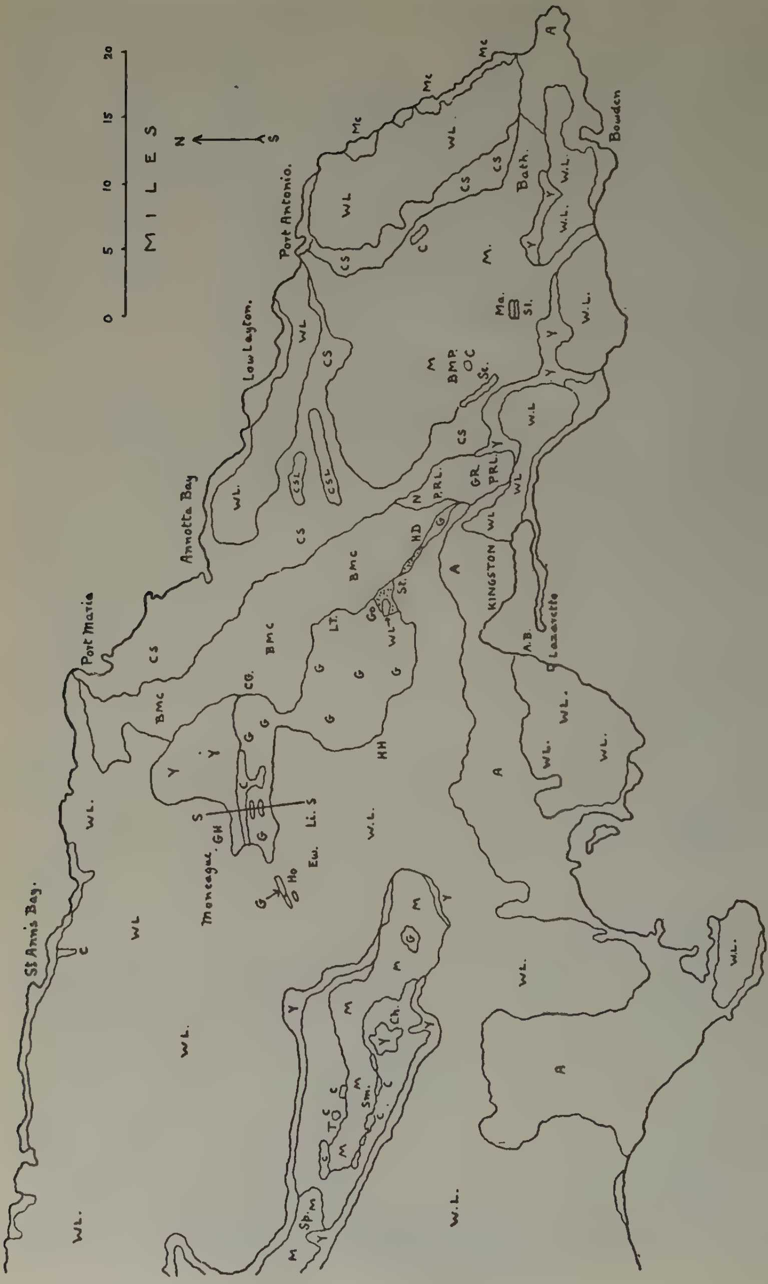
Covering these older folded beds comes the Yellow Limestone (Lower Lutetian) followed by the 2,000 feet or more of White Limestone (Upper Eocene–Lower Miocene).

It may here be mentioned that near the edges of the escarpment of the White Limestone it is often advisable to look at sections with a good deal of caution. The slopes are often very steep and the rainfall intense, and large masses of White Limestone have sometimes slipped or become displaced over the adjacent beds which may in some cases be gravels of a much later date. I once published[1] a sketch showing a mass of White Limestone which had crept and come to rest on Cretaceous and Eocene beds near Catadupa giving a deceptive junction.

Much of the earlier folding and shearing is of late Cretaceous to early Eocene age (pre-Lutetian). The large granodiorite-porphyry

---

[1] GEOL. MAG., LIX, 1922, p. 428.


MILES
0 5 10 15 20
N
S
Port Antonio.
Low Layton.
Annotta Bay
Port Maria
St Ann's Bay.
Moneague
Bath.
Bowden
KINGSTON
Lazarette
A.B.
WL
W.L.
CS
CSL
BMC
BMP.
OC
St.
Mc
M.
Ma.
Sl.
Y
C
A
G
CG.
LT.
Go
HD
HH
N
PRL.
GR.
GH
S
Li. S
Ew.
Ho
Ch.
T
Smi.
Sp.m

intrusion and the present dome-like structure of the island date from late Oligocene to Miocene times (pre-Middle Miocene or pre-Bowden beds). The latest igneous eruptions are the Low Layton pillow lavas on the north-east coast which are associated with white marls which are Miocene and just earlier than the Manchioneal beds (Lower Pliocene ?).

CONGLOMERATES IN JAMAICA.

There are three chief conglomerate facies ; I have never seen a conglomerate in the White Limestone, nor any indication of the proximity to a shore line.

1. The Bowden conglomerates, associated with the Bowden shell beds (mid-Upper Miocene) in South-East Jamaica ; they are mostly made up of small fragments of porphyry, jasper, quartz, slaty rocks etc. They inaugurate the marine phase of the Bowden and Manchioneal beds.

2. The conglomerates associated with the Carbonaceous Shale or Richmond beds and leading to the increasingly marine deposition of the Yellow and White Limestones. They yield rolled Cretaceous Rudists etc., together with Eocene marine and freshwater mollusca, and comprise pebbles of gneiss, schist, granite, porphyry, lavas, agate, quartz etc. The gneiss and schist pebbles have been assumed to indicate the presence not far away of some ancient land mass, but in view of Palmer's[1] statement that in South Mexico the Cretaceous (Cenomanian) beds are altered into gneisses and schists one may perhaps question whether these pebbles in the Carbonaceous shale conglomerates are necessarily Archaean or even Palaeozoic in age.

3. The great Blue Mountain or purple conglomerate which is associated with marine Cretaceous shales and limestones. The pebbles are much less varied than in the Carbonaceous shale conglomerate. I have never seen any of the gneiss or schist in it and very

---

[1] "The Rudistids of Southern Mexico," *Occasional Papers California Acad. Sciences*, 1928, xiv, p. 8.

TEXT-FIG. 1.—Sketch-map of Eastern part of Jamaica (based on Sawkins). Plain areas round coast, White Marls and raised Coral Rock. A, Alluvium ; Mc., Manchioneal beds ; Dotted, gravel beds ; W.L., White Limestone ; Y., Yellow Limestone ; C.S., Carbonaceous Shale or Richmond beds ; C.S.L., Limestone in the latter ; C., Cretaceous Limestone and Shale ; B.M.C., Blue Mountain conglomerate ; G., Granodiorite etc. ; Se., Serpentine ; Ma, Marble ; M., Metamorphosed series. Localities : P.R.L., area of the Port Royal Laccolite ; G.R., Guava Ridge ; B.M.P., Blue Mountain Peak ; A.B., Apostle's Battery ; S.I., Serge Island ; Li., Linstead ; Ew., Ewarton ; G.H. Guy's Hill ; Go., Golden Spring ; T., Trout Hall ; L. T. Lawrence Tavern ; Ch., Chapelton ; Sm., Smithville ; Sp., Spaldings ; H.D., Hermitage Dam ; H.H., Harker's Hall ; N. Newcastle ; Ho., Hollymount ; C.G., Castleton Gardens ; St., Stony Hill ; SS., section from near Linstead to Guy's Hill.

few if any of granite. Limestone pebbles occur in some localities in Eastern Jamaica and at three or four places I have detected organisms in them.

LIMESTONE PEBBLES IN THE BLUE MOUNTAIN CONGLOMERATE.

After considerable searching limestone pebbles containing structures were found near the Hermitage Dam and along the Wag Water River at one or two places near the Castleton Gardens. Below Gordon Town there are large blocks of limestone in the conglomerate but they seem to be devoid of organisms.

The pebbles yielded no large fossils; one found near Castleton Gardens is a dark red oolitic limestone. The organisms so far determined are: Foraminifera; *Textularia* sp.; *Cristellaria* (?) indeterminate; *Amphistegina* (?); Echinoderm plates and spines (cross sections); and many fragments of *Lithothamnion* spp. and allied structures. I understand[1] that *Lithothamnion* occurs commonly only from the Aptian upwards, so that we seem to have pebbles not older than Middle Cretaceous in a presumably Upper Cretaceous conglomerate. Slices of these Jamaican lithothamnial pebbles look very like those illustrated from the Ronde Klip conglomerates[2] of Curaçao, which contain *Lithoporella*, *Lithophyllum*, and *Amphiroa*. In Curaçao the Knip lagen or Ronde Klip lagen are attributed (with a question mark) to the Cretaceous, and are placed below the Seroe Teintje Limestone, which is attributed to the Lower Senonian.

THE "METAMORPHOSED SERIES" OF SAWKINS.

(*M.M. on Sketch-map, Text-fig.* 1.)

Sawkins frequently refers to these rocks, with such remarks as "shales have been converted into grey porphyritic masses with difficulty distinguishable from the igneous rock itself". Matley (p. 475) says "A group of red-weathering andesitic lavas and tuffs, with associated intrusives, are described. They underlie the Upper Cretaceous conglomerates; but it is not yet known whether they are of Cretaceous age or belong to the Complex." Higham's petrological notes in Matley's paper (p. 487) seem to include examples of these rocks.

They occupy large areas of Eastern and Central Jamaica, especially the Blue Mountain country and the central inlier of the Rio Minho and Arthur's Seat area, adjacent to the outcrop of the granite complex, or where granite or other intrusive masses might be expected to occur below the surface. They are not seen in Western Jamaica west of a line drawn from Rio Bueno southwards to Mandeville.

---

[1] I am indebted to Dr. H. D. Thomas and Mr. W. N. Edwards of the British Museum (Natural History) for kindly helping me with these rock slices.

[2] G. J. H. Molengraaff, *Geologie en geohydrologie van Het Eiland Curaçao*, Delft, 1929, pp. 22 and 29, pl. v.

Slices of the fresh pebbles show that to an ordinary observer the rock is apparently an " andesite ". They are apparently the result of some process of metamorphism but until some petrologist makes a definite pronouncement, aided perhaps by chemical analysis, their mode of origin remains obscure. In the field they are recognized by the various bright colours of the different pebbles or layers. Tropical weathering reduces the pebbles to a soft lateritic material which is dug out with spades in road cuttings ; otherwise the pebbles when fresh are very hard and difficult to break. They show very fresh transparent felspars and perfectly developed and terminated crystals of opaque ferruginous brown " augite "[1] ; rounded quartz grains are rarely visible. The glassy-looking crackly fresh felspar is a striking contrast to the turbid decomposed felspar one sees in the porphyritic pebbles in the ordinary Blue Mountain conglomerate ; the rock also tends to break at the angles and faces of the augites and not across them.

Metamorphosed series are well seen in the Rio Minho inlier, especially north of Spalding's ; near Smithville ; and at intervals from Trout Hall to Chapelton, and at Crooked River west of Trout Hall ; at Arthur's Seat, and other places. In the Rio Minho Valley Sawkins maps the metamorphosed series as though it were underneath and surrounded by an oval ring of interrupted outcrops of Cretaceous limestone. To the north-west of this, at Spalding's and also south of Smithville it occurs at a higher level than the Cretaceous limestone ; possibly the limestone outcrops may be repeated by faulting in this district.

At Crooked River some of the pebbles in the conglomerate seem to be metamorphosed but others not, as though some selective action had taken place ; and in these pebbles rounded quartz grains are invaded by portions of the magma, but whether this is an original feature or a later metamorphic effect seems hard to say.

The following alternative explanations seem possible to explain the peculiar occurrence of the metamorphosed series :—

1. That they are ordinary conglomerates and fragmental bedded series which have been changed *in situ* to a material resembling andesite. This seems to have been Sawkins's view.

2. That they are andesitic agglomerates and ashes re-heated and the felspars and augites " freshened up " *in situ*.

3. That some re-heating took place elsewhere and the material was denuded and re-deposited as these conglomerates. This does not however satisfactorily explain the remarkable glassy freshness of the felspar crystals.

---

[1] The precise nature of this ferromagnesian mineral has not yet been determined.

SERPENTINE INTRUSIONS.

I noticed a dyke about 40 feet wide of greenish serpentinous-looking material among the Cretaceous rocks 4 miles north-west of Chapelton on the road to Trout Hall; and another similar but smaller dyke cutting Cretaceous shales about 3½ miles west of Bath along the Plantain Garden River. These dykes are probably too much decomposed for any satisfactory petrological determination, but if not actually of serpentine they seem to imply that the serpentine of the more metamorphosed areas south of Blue Mountain may also be of Cretaceous or later age and need not necessarily indicate a Jurassic or old basal complex age.

THE SERGE ISLAND MARBLE.

(*S.I. on map,* 20 *miles East of Kingston.*)

Sawkins maps two patches of "marble" or "marmolite" (coloured a dark green on his map) adjacent to masses of serpentine about 4–5 miles south and south-east of Blue Mountain Peak; one of these is the Serge Island marble. He indicates them as occurring among "metamorphosed series" but parallel to the line of strike of the Carbonaceous Shale or Mount Hybla beds. When the Carbonaceous Shale occurs at high levels in the Blue Mountain country Matley (p. 451) calls it, or a portion of it, the "Mount Hybla group". Matley describes the Serge Island occurrence on page 461 and claims the marbles and associated beds as "another group of the Basal Complex"; Stockley, on the other hand, states his opinion that these beds are metamorphic derivatives of the Blue Mountain series.

The various rocks are well seen at the Serge Island Dam and the War Memorial at Kingston is faced with marble from this locality. Below the Dam in the stream there is a greenish fractured rock, not a marble, as it is insoluble in dilute acid, looking rather like an ancient Welsh slate, and loose in the stream are many boulders of this and of sheared and twisted red, white and green marble, serpentinous and chloritic marble and various igneous rocks derived from higher up.

From its position and appearance I am inclined to conclude that the Serge Island marble is a metamorphosed equivalent of the unfossiliferous limestone which occurs in considerable thickness in the Carbonaceous Shale Series (Basal Eocene) of the Blue Mountain area. Accompanying or subsequent to the major intrusions there was no doubt thrusting, probably in a northerly direction, in the region south and west of Blue Mountain Peak, which has caused the shearing of the Serge Island marble and associated beds.

THE GRANITE JUNCTION ALONG THE WAG WATER RIVER.

(*Go-L.T. on map.*)

The large granite or granodiorite mass of Jamaica at its easterly boundary is well exposed in the bed of the Wag Water for about 3 miles near Lawrence Old Tavern on the road from Stony Hill northwards to Annotta Bay. At both ends of its margin it is (to me) quite clearly intrusive against and into the Blue Mountain purple conglomerate. Dr. Matley in his paper (pl. xxiii and pl. xxiv, fig. 1) indicates this granite-conglomerate junction as a " thrust ".

At its more northerly boundary, about 1½ miles north-east of Lawrence Tavern, a section in the river shows the purple conglomerate twisted, crushed and veined and invaded in all directions for some yards by the lighter-coloured igneous veins; some of these are porphyritic and others of the granite, which is quite coarsely crystalline and has taken on a gneissic nature as a result of squeezing into the rock. A tongue of granite 3–4 feet thick passes almost horizontally over and into the purple conglomerate at one point.

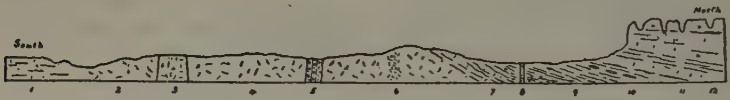
Its southerly contact is seen in the river a little north of Golden Spring, where a stream called the Iron River joins the Wag Water, and near a small bridge and along a road leading to Mount James. The Blue Mountain conglomerate is crushed to a green and purple mass for several feet away from the granite but further up the road it becomes quite normal and uncrushed. In the small stream strings and veins of coarse grained granite are seen penetrating the crushed conglomerate.

GUY'S HILL AREA. PARISHES OF METCALF AND ST. THOMAS IN THE VALE.

(*Section SS on map, and Text-fig.* 2.)

The large granodiorite-porphyry complex extends north-westwards as a strip about 2 miles wide from south to north; a road from Linstead northward to Guy's Hill crosses it and exposes a good section. On the south of the igneous mass lies the White or Yellow limestone, while north of it comes Cretaceous limestone followed northwards by Yellow and then by White limestones. Sawkins indicates it as " Granite and Syenite " and places upon it two or more elongate east to west oval patches of Cretaceous limestone (coloured blue). Looking at his map one might judge these to be outliers of limestone resting on the granite; in reality on reaching the locality one perceives that they are two or more masses of the Cretaceous and probably also of Tertiary limestone which plunge steeply down into the igneous rock and become completely hornfelsed. The bedding of at least the northerly of the two strips is entirely preserved but no trace of fossils remains.

The igneous rock is a grey quartz-porphyry merging into a granite with sub-ordinate red-brown porphyry, all considerably decomposed. Going northwards along the road about 4 miles north of Linstead the actual southern junction with the Tertiary limestone could not be seen, but a little north of this, near a stream comes the igneous rock and then a considerable width of hard streaky and splintery hornfels, apparently altered White or Yellow limestone; then more granite and quartz-porphyry and then two successive strips of thinly bedded nodular-looking rock of yellowish or greenish streaky hornfels type dipping almost vertically into the igneous mass. Then follows more quartz-porphyry and northwards the igneous complex is succeeded by darkened but little altered Cretaceous limestone, ashy and impure in parts, but with many sections of Rudists and Actaeonellae. North of this come purple conglomerates cut by one or more porphyry dykes, followed by the Yellow Limestone around Guy's Hill and finally the White Limestone which forms the wooded heights north of the igneous inlier.



Text-fig. 2.—Diagrammatic section across the Granodiorite outcrop from near Linstead northwards to Guy's Hill, to show the relation of the sedimentaries to the igneous rocks. Length of section about 4 miles. SS, on sketch-map. 1, White Limestone; 2, granitoid porphyry; 3, streaked massive hornfels; 4, syenitic rock with porphyry; 5, bedded nodular hornfels, apparently altered Cretaceous limestone; 6, red porphyry associated with granodiorite; 7, dark Cretaceous Rudist limestone, ashy in places, quarry; 8, red porphyry dyke, cutting shale and conglomerate; 9, purple shales; 10, nodular Yellow Limestone, Eocene; 11, Yellow shales and limestones; 12, White Limestone, "Cockpit" or "Karst" country.

Hollymount and Mount Diablo.

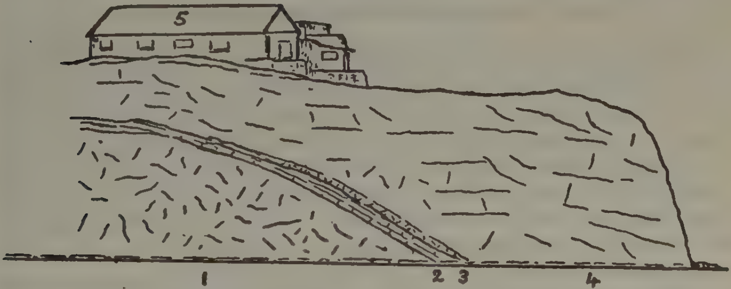
(*Ho. on map, south of Moneague.*)

Between Ewarton and Moneague Sawkins maps an elongate strip a mile long of "Granite and Syenite" and adjoining it two or three strips of "Cretaceous limestone" (blue) lying as inliers among the White Limestone. The igneous rock is evidently a south-westerly continuation of that just described whose nearest outcrop is 2–3 miles to the north-east. I several times searched the dark-coloured limestone here for Cretaceous fossils but without success and concluded that the blackening is an effect of the intrusion on the adjacent White Limestone. The section can be seen in the roadside near Hollymount but is decomposed and rather obscured. A dyke or dykes or at any rate an intrusion about 40 yards wide partly of dark red porphyry and partly of light-coloured quartz-porphyry merging into granitic material occurs; the White limestone on either side is fractured and darkened but apparently not hornfelsed.

THE LAZARETTO, NEAR PORT HENDERSON; WEST SIDE OF KINGSTON HARBOUR ENTRANCE.

(*Text-fig.* 3.)

Matley (p. 458) illustrates a drawing of a section in Green Bay, near Apostle's Battery, south of Port Henderson in the Healthshire Hills. It represents a very regular anticline of White Limestone resting on an equally regular core of " well foliated green hornblende-schists and amphibolites ", which is made to appear as if it extended down to sea-level, though on reading the text one gathers that this was not observed to be the case. This underlying core is said to be part of the basal complex but no " basal bed containing schist pebbles " was observed and " the coincidence of limestone dip with schist-foliation dip " is stated to be merely " a geological accident ".



TEXT-FIG. 3.—Section below the Lazaretto, Kingston Harbour.

1. Hornfelsed and darkened limestone, veined and fractured.
2. Marmorized limestone, white or grey and streaky marble in regular layers.
3. Broken up crushed yellowish dolomitized limestone.
4. White Limestone, massive and bedded in places, broken up in some parts.
5. The Lazaretto, about 40 feet above sea-level.

I could find no hornblende-schist in this locality, but some of the hornfelsed rock at the side of the Lazaretto was sheared and streaked in a way suggestive of such a rock. Viewed from the sea, the whole Port Henderson massif looks like an undisturbed dome of White Limestone, and it is only on closer inspection that one notices that there is something unusual here.

On the slope at the side of the Lazaretto the section is weathered and obscured, but if one climbs down one finds below the Lazaretto a sea cliff which shows a much better section and immediately convinces one that the affair is an effect of intrusion. The cliff here is about 40 feet high and shows at the base a mass of broken-up hornfels-like rock which passes up into a grey and streaky or in places a white glistening marble[1] in a regular layer 1–2 feet thick. This marble is overlain by a few inches of a friable broken-up yellowish dolomitized limestone and this passes up into the ordinary White Limestone which is broken in some places but bedded and massive in others. There is probably some intrusion not far away but the only igneous material I could find was a decomposed greyish porphyritic rock associated with rotted hornfels up the slope behind the Lazaretto. The half-amphitheatre-like structure of Green Bay seems to be due to weathering out of the broken-up hornfelsed rock.

It is due to Dr. Matley's energy that we are aware that there is something unusual connected with the White Limestone in this locality, but his statement (p. 449) that "the White Limestone is never thermally altered" certainly does not apply here.

THE RIO PEDRO AND THE ROAD FROM STONY HILL W.N.W. ABOUT 10 MILES TO HARKERS HALL.

(*St.-HH on map, 12 miles north-west of Kingston.*)

This is a critical area for the interpretation of Jamaican structure. Near Golden Spring,[2] about 1½ miles north-west of Stony Hill, one comes to the bed of pebbles which Matley interprets as a basement Eocene conglomerate of the White Limestone. The conglomerate bed comes above the granite, which is therefore concluded to be an old basal complex, a supposition encouraged by the fact that the conglomerate contains granite pebbles. Sawkins maps these conglomerates as gravel beds later than the White Marl, which itself is later than the White Limestone.

Here on the edge of a very steep slope one sees about 25 feet of a rotted rubbly and badly assorted conglomerate made up of angular and rounded pieces of granite, porphyry, a few of hornfels, and various other rocks. Above the gravel lies a large mass of White Limestone which Matley (p. 448 and pl. xxiii) indicates as an outlier, but which seems to me to be a mass that has become detached from the main escarpment and crept over part of the gravel bed. Two miles or so further along the road this gravel bed gives place to or merges into a reddish lateritic bed.

About a mile further on from the conglomerate section, at a projecting elbow of the road and about two feet above it, an ill-defined broken-up band of whitish limestone about twenty feet long and two feet thick appears among the gravel conglomerate and seems to merge into it at the edges. This may be the same bed as that described by

---

[1] Specimens of these and other rocks mentioned in this paper were collected, and may be investigated by anyone interested.

[2] Dr. Matley calls the place "Golden Hill", but "Golden Spring" is the name that appears on Sawkins's map.

Matley (p. 448) who, in referring to Sawkins's attribution of these conglomerates as old river gravels of the Wag Water, says "the discovery in them of an impersistent limestone-band (with sandy seams) about 4 to 6 inches thick, and composed mainly of corals effectively disposes of this hypothesis." Both *in situ* and in thin section this bed looks to me like a calcrete of broken-up and partly dissolved White Limestone; I found what appears to be a piece of the marine gasteropod *Orthaulax* and other organisms in it, and it is in parts full of rubble and small pebbles.

A great deal of fresh and decomposed dark green hornfels occurs about here. One is evidently near the top of the granite mass and I interpret the hornfels as masses of limestone or other overlying rocks that have sunk into it. Sawkins refers to it (p. 107) as Petrosilex. Higham, in Matley's paper (p. 482, KP. 147 and 166), describes what appear to be specimens of these rocks. Near a place called Above Rocks a purple porphyry is associated with the granite, but I could see no definite dykes cutting the granite.

Towards Harker's Hall more or less banded hornfels is strongly in evidence and at one place there is a cliff of hornfels with lumps of a dark greenish coarsely crystalline sheared hornblendic rock embedded in it; one might almost describe it as a hornblende-schist and it seems to be a modified offshoot of the granodiorite. Near this locality the hornfels is pebbly, and the streaky bands in it seem to be due to melting and drawing out of the pebbles. At Harkers Hall very fresh and hard granite or granodiorite is exposed in the river bed and the White Limestone follows immediately above it. A recent roadside cutting shows the granite sending a projection some 50 feet wide for about 30 feet up into the White Limestone; the granite is decomposed but the effect at its outer contact seems to be only a partial dolomitization and breaking up of the limestone.

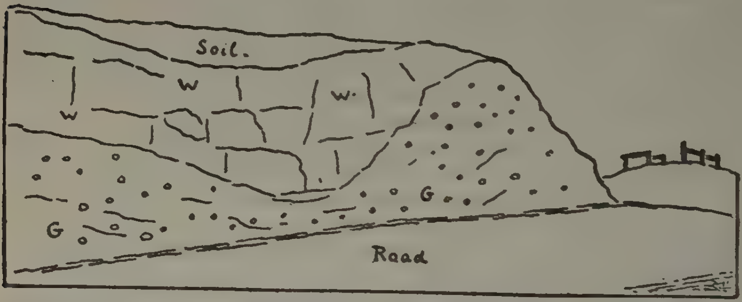
We are here near the south-western corner of the granite outcrop and on the right side of the river a thick well-bedded fossiliferous, rather dolomitic limestone occurs; the actual contact was obscured but I was evidently only a few inches from it. This limestone looks rather like the Yellow Limestone, but it may be a higher bed or part of the Montpellier series; it has bands of lignite with flakes of carbonaceous material and marine fossils in it, and at some places it tends to become dark, saccharoidal, and dolomitic. It has been tilted in various directions but the dip on the right side of the river is away from and off the granite, the strike of the bedding remaining parallel to the granite margin.

The deceptive feature of this and similar sections in Jamaica seems to be that while the granite has thoroughly hornfelsed beds that have fallen or become pendent in it, at the outer contact the effect has been little more than a crushing, dolomitization, or limited marmorization of the rock. A similar feature reported from the Island of Porto Rico will be mentioned later on.

THE HERMITAGE DAM AREA, 7 MILES NORTH OF KINGSTON.

(*H.D. on map.*)

This area is described by Matley (p. 449) where he mentions "a rupture, probably a high-angled thrust, which brings the complex partly against the Purple Conglomerate group and partly against the red or purple andesites which underlie the base of these conglomerates. Along its south-eastern boundary the White Limestone is seen, with its base exposed in places and showing underlying beds of clay, pebbly grit and coarse conglomerate."



TEXT-FIG. 4.—Section on roadside near the Hermitage Dam, Jamaica. WW, White Limestone slipped over late gravel beds, GG. Sketched from a photograph.

My observations were as follows: Beyond the place where the new road up to the Dam leaves the White Limestone escarpment there is a bed about 20 feet thick of rubbly conglomerate, much decomposed, made up of various pebbles including some of granite. Masses of White Limestone have slipped or crept over part of this gravel bed which lies near the edge of a very steep slope down to the Wag Water River (see Text-fig. 4). Further along the road before reaching the Dam the junction of the granite with the Blue Mountain conglomerate is seen; the junction is too heavily weathered to give much information, but the granite near it becomes rather slickensided and the conglomerate for 70 feet or so is altered to a greenish or purplish broken-up material. Further on the purple conglomerates are unaltered and consist of iron-coated or malachite-impregnated pebbles of red porphyry, a few quartzose or slaty rocks or vein stuff, and a number of limestone pebbles some up to a foot in size, including marmorized or haematitic limestones containing lithothamnial and foraminiferal structures. I saw no granite or gneiss pebbles in the true undisturbed Blue Mountain conglomerate. The dam has been constructed among the great mass of these purple conglomerates, or blue beach as they are sometimes termed.

THE PORT ROYAL "LACCOLITE". GORDON TOWN—GUAVA RIDGE—MAVIS BANK AREA.

(*P.R.L. on map, 7 miles north-east of Kingston.*)

A ridge about 3,500 feet high some 8 miles E.N.E. of Kingston is made up of a mass of igneous with subsidiary sedimentary rocks. Sawkins does not differentiate it from his "Metamorphosed Series" and seems to have regarded it as an altered sandstone. Matley (p. 443) refers to it as a porphyry intrusion admittedly post-basement in age. Stockley calls it the "Port-Royal Laccolite", and says its area covers about 200 square miles and goes on to say that it is just possible that it was originally a sill and its laccolithic appearance more apparent than real, this appearance being the result of a north-west thrust.

However this may be, the greater part of the massif consists of undoubted porphyritic igneous material of fairly uniform composition with little or no visible quartz; and it is clearly an intrusion into the Blue Mountain and Carbonaceous Shale formations.

Above Gordon Town on the road to Guava Ridge a junction with the Blue Mountain conglomerate is seen and curiously a quantity of gypsum occurs at the junction; the beds are all nearly vertical and are arranged as follows:—

Decomposed Porphyry	Crushed red and grey shale and conglomerate. 45 feet.	Sheared grey impure gypsum. 15 feet.	Crushed conglomerate 10 feet.	Purple Blue Mountain conglomerate, uncrushed.

After leaving this junction we are well among the mass of the "laccolite" and further along the ascending zig-zag road there is a curious patch about 30 feet thick of very regularly bedded grey shales, apparently part of the Carbonaceous Shale or Richmond beds. These dip about 40° N.N.E. and comprise thick coarser beds and thin dark finer shales and seem to be incorporated and to merge into the igneous mass. The rock is not at all fresh but the coarser beds appear to have been changed into a material almost identical with the porphyry and actually seem to grade away into it.

Before coming to Mavis Bank a dark-coloured limestone is also semi-incorporated among the porphyry; the limestone is unfossiliferous but seems to belong to the Carbonaceous Shale series. It is about 30 feet thick, and dips very steeply north-east and is followed by a few feet of purple shale. The porphyritic rock occurs on both sides and portions of it have invaded the limestone along the bedding, and near the edge the limestone is impregnated with spots and patches of pale-coloured igneous material.

These large-scale inclusions or assimilations of sedimentary rock suggest that, although the main mass of the porphyry shows an intrusive contact, Sawkins's term "Metamorphosed" Series may be a more appropriate term for parts at least of it than "Sill" or "Laccolite".

WESTERN JAMAICA.

This region is comparatively undisturbed, but the dips of the older rocks including the Carbonaceous Shale are often considerable; the intrusions consist of minor dykes which generally do not penetrate the Yellow Limestone. Neither granite nor "Metamorphosed" series is seen. In the Cretaceous inliers—the Great River Valley, Haughton Hall or Green Island, Malden area, and Jerusalem Mountain in the far west—large fossils such as Rudists can be obtained uncrushed.

The contrast between the western half which rises only to about 2,500 feet and the much intruded and tectonically involved eastern end of Jamaica which rises in mountains up to 7,200 feet in height is very striking.

THE ISLAND OF PORTO RICO.

H. A. Meyerhoff,[1] after mentioning several recent finds of fossils of Upper Cretaceous age in the older rocks of Porto Rico says:—"Matley's and Earle's opinion that pre-Mesozoic materials are present in Porto Rico and the Virgin Islands is without foundation, other than the physical appearance of some of the rocks. The palaeontological and stratigraphic data now at hand, although incomplete, indicate that all the ancient sediments and associated volcanic and intrusive igneous rocks are Upper Cretaceous, not only in Porto Rico but also in the Virgin Islands."

Chas. P. Berkey,[2] referring to the numerous intrusions says: "The number and complexity of the igneous intrusions are surprisingly great and at many places the intrusive members dominate in the formation. In most cases there are no noticeable contact effects." He goes on to say:—"Much larger intrusive sills, which are almost always dioritic in composition, are also very common and there are a few large bosses several miles across of granite, syenite and serpentine."

CONCLUSIONS.

1. No natural base of the Blue Mountain Series is known in Jamaica. The oldest fossils found *in situ* are Upper Cretaceous (*Parapachydiscus*, *Inoceramus* cf. *balticus* and other Senonian forms).

2. The pebbles of the Blue Mountain conglomerate seem to comprise more or less contemporaneous material: the limestone

---

[1] *Science*, 75, March, 1932, pp. 342–3.

[2] "Introduction to Geology of Porto Rico," *Dept. Geol. Columbia University Publications*, xxvii, No. 35, 1919, p. 19.

pebbles yield only oolitic, lithothamnial, foraminiferal and other remains. Hopes of finding anything Palaeozoic in it were disappointed.

3. The large granodiorite-porphyry bathylith is intruded into Cretaceous and Tertiary beds as high as well up in the White Limestone (Oligocene or Lower Miocene). It is not an ancient basal complex, but is one of the newer igneous rocks : it hornfelses masses of sedimentaries that have fallen into it, but at its outer contacts the effects are relatively so slight as to be often inappreciable.

4. The supposed basal conglomerates of the White Limestone at Stony Hill and the Hermitage Dam are late re-assorted gravel beds partly covered by displaced masses of White Limestone. The reported basal hornblende schist occurrence at the Lazaretto is an intrusion effect.

5. The Serge Island marble is probably altered limestone of the Carbonaceous Shale or Richmond beds ; and the serpentines or green serpentine-like intrusions and dykes are not necessarily pre-Cretaceous in age.

6. In the writer's opinion no evidence of any old pre-Cretaceous basement has yet been found in Jamaica.

Memorandum on an Excursion to Newry Igneous Complex, Co. Down, August, 1935.

By Professor E. B. Bailey.

LAST summer Miss D. L. Reynolds kindly organized an excursion of ten, all told, to discuss her recent paper on " The Eastern End of the Newry Igneous Complex " (*Quart. Journ. Geol. Soc.*, xc, 1934, p. 585). We were introduced in most helpful fashion to both field exposures and microscope slices. In some particulars, differences of interpretation arose ; and at the conclusion I circulated a brief memorandum. This by request I now offer, with trifling changes, for publication. Page and figure references, unless otherwise defined, apply to Miss Reynolds's paper.

(1) As a matter of field observation, backed by microscopic examination, I accept the contention that much igneous material has marginally entered the contact zone of the sediments ; also that it is probable that this penetration has occurred to some extent molecularly without disruption of bedding ; also that solution of sediment has to some extent modified the invading igneous material with production of such minerals as cordierite ; also that this type of penetration can be found at contacts which have not been reached by the main granodiorite intrusion.

Where shown marginal breccia I usually felt that one could see modified igneous material invading modified sediment. In conversation Miss Reynolds claimed that hornblende porphyroblasts have developed in *bedded* hornfels in the Rough Hill area (the description on pp. 612–13 is less definite). A slice that I was shown to illustrate this point seemed to me to be essentially igneous and to record a complicated history of crystallization and reaction of the ferromagnesian constituents.

(2) While agreeing that very often the igneous rocks of the region contain recognizable sedimentary xenoliths, I had to dissent in regard to certain identifications. (*a*) In an association of altered greywacke and various igneous types including biotite-pyroxenite (south of a bridge, pp. 589, 618), what I should call an igneous vein cutting other types has been described as a " raft " of sediment " highly crystalline with porphyroblasts of felspar ". (*b*) Pseudomorphs after olivine seem to be widespread in the igneous rocks, and to have been identified as " relics of augite-hornfels ", fig. 9 on p. 615. This point will be discussed under heading (6).

(3) On looking through the slices many of the basic rocks seem perfectly normal gabbro-diorites, without even marked reaction or contact alteration. Fig. 8 is probably representative. Similar rocks are common in Argyll (Arrochar and Ballachulish), as also are other varieties showing reaction and contact-alteration. The biotite-pyroxenite is an extreme type, not fully represented in Argyll, but it is obviously closely related to its associates.

(4) Our short visit proved that some of the rocks mapped as diorite and monzonite are very near in composition to the biotite-pyroxenite, while others are very much richer in leucocratic constituents. We sometimes saw sharp contacts between non-felspathic and felspathic types, but we did not have much chance to test the significance of this observation. From what I saw in the field, combined with microscopic evidence, I am convinced that there has been important migration of leucocratic material within the igneous complex. Miss Reynolds also postulates internal migration of leucocratic material, when she claims that her augite-biotite-diorite type has been derived from the biotite-pyroxenite through introduction of felspar, see (5).

(5) Miss Reynolds bases her hybrid explanation of the augite-biotite-diorite type upon exposures west of Backaderry Road (pp. 588–9). Here she describes " distinct veins and small dykes " of plagioclase rock, sometimes cutting biotite-pyroxenite, sometimes grading through augite-biotite-diorite into biotite-pyroxenite. and claims that it is clear that the augite-biotite-diorite has " resulted from the permeation of the ultrabasic rock at least after partial crystallization by a plagioclase magma and consequent reaction ". I may point out that the exposures are exactly analogous to those shown by many slowly crystallizing magmas in which differentiation has been favoured by a considerable gap between the crystallization temperatures of the early crystals and the residual melt. Often, as where the leucocratic material, here mostly plagioclase with biotite,

occurs as distinct pegmatitic dykes, there may have been considerable migration; elsewhere, where the veins are indefinite, the travel may have been small. The matter is discussed by H. H. Thomas and myself in the Geological Survey Memoir on Mull, where special reference is made to the Linlithgow sills of quartz-dolerite (Mull, 1924, p. 330). When allowance is made for differences of composition the Mull discussions (Mull, pp. 324, 329, 355) have a close bearing upon the Newry phenomena. For further descriptions of the veining of the coarse quartz-dolerite sills of Scotland (quite impossible, in my opinion, to attribute to outside interference, but represented by both vague and definite types of veins comparable with those at the Backaderry road) see Falconer in *Trans. Roy. Soc. Edinb.*, xlv, 1906, pp. 137, 147. Without leaving the local exposures one may record a rather significant observation. One of the pegmatites, containing plagioclase, biotite, orthoclase, and quartz cuts a rock containing augite, biotite, and plagioclase. The plagioclase of this latter is not supplied by the vein, for the vein is rimmed by a couple of inches of reaction border in which the ferromagnesians are recrystallized to acicular hornblende and the plagioclase to plagioclase moulded upon this hornblende. There has been a certain amount of material introduced, including volatiles and quartz, but it is self-evident that plagioclase occurred previously to this introduction and has been modified. The kentallenite-aplites (Geol. Surv. Mem. on Ben Nevis and Glen Coe, 1916, pp. 140, 171) also sometimes alter their host at contact.

(6) Miss Reynolds bases a hybrid explanation of the augite-monzonite type mainly upon micro-sections. She claims that the monzonite has resulted from permeation of sediments by biotite-pyroxenite magma, sometimes already modified by plagioclase magma (p. 619). A feature of the type is the occurrence of big augites. In many cases these have crenulate margins and sieved interiors; and Miss Reynolds interprets them as ill-formed porphyroblasts, comparable with the garnets of schists. She thinks that they are among the latest crystallizations of the rock. The alternative view is that these ragged augites are corroded phenocrysts, and are among the earliest crystallizations. In one observed case the crenulate borders abruptly cross zoning marked by iron ore, and corrosion seems certain. Let us, however, draw attention to another feature of these rocks, which has only been partly appreciated. Olivine is fresh in certain slices from Newry, and has been recorded by Miss Reynolds (in peridotite, p. 604; augite-biotite-diorites pp. 609, 612; augite-monzonite, p. 613). On looking through the slices I found that pseudomorphs after olivine (some may be after hypersthene) are common, though not interpreted as such: "Aggregates of actinolite associated with iron ore" in biotite-pyroxenite, p. 607; "clusters of augite granules (relics of augite hornfels)" in augite-monzonite, fig. 9 and p. 615; "aggregates of a pale actinolitic hornblende" whose "origin can at times be

traced to the aggregates of augite granules ", p. 615. I may here note that S. R. Nockolds, who attended the excursion, recognized that the granules are enstatite, not augite. The frequent presence of olivine, fresh or decomposed, in the augite-monzonites is of prime importance in the discussion of the large augites, for it seems necessary to assume that the olivine at least has crystallized from a melt.

(7) Many of the augite-monzonite suite, even where they contain fresh olivine, also contain abundant micropegmatite. This has been called myrmekite by Miss Reynolds (p. 616), though I do not quite like the name, as the material does not resemble closely the myrmekite with which I am familiar in Scotland. One olivine-rich slice may be taken as a type. The olivine is mostly fresh, though encased in reaction products. The micropegmatite is so abundant that it is inconceivable that its material was present when the olivine crystallized. One finds therefore conclusive evidence of migration of early crystals relative to melt (presumably residual melt). The corrosion of augite and the frequent replacement of olivine by amphibole aggregates are exactly what one would expect under the circumstances. Useful suggestions regarding honeycomb corrosion may be gathered from A. G. MacGregor (*Trans. Edinb. Geol. Soc.*, xii, 1932, p. 329).

(8) The conversion of the amphibolic pseudomorphs after olivine into enstatite granules is more than mere reaction between early crystals and residual melt, with falling temperature. It suggests rising temperature; and in keeping with this one finds that the associated plagioclases show clouding of contact type. As might be expected in an igneous complex, quite a number of the slices show this and other features of contact alteration. It is perhaps well to state that there are two very distinct types of cloudiness illustrated in these slides: decompositional cloudiness marked by sericite, zoizite, etc., and contact cloudiness due to minute opaque rods. Contact cloudiness has been discussed by A. G. MacGregor (*Min. Mag.*, xxii, 1931, p. 524).

(9) I am of opinion that the basic rocks at the east end of the Newry complex are full of illustrations of differentiation by crystallization coupled with the necessary concomitant reactions. These principles are of old standing in petrology, and have been elaborated with particular care by N. L. Bowen.

In writing this memorandum I have not consulted other members of the party, but I am sure from discussion during the excursion that most of them have come to similar conclusions.

The Structure of *Oncograptus* T. S. Hall.

By O. M. B. Bulman, Sedgwick Museum, Cambridge.

Introduction.

THE genus *Oncograptus* was founded by T. S. Hall (1914, p. 109) with the species *Oncograptus upsilon* T. S. Hall as type. The original definition reads: "Hydrosome at first biserial, but later dividing into two uniserial branches. Thecae long, narrow, and slightly curved. The form of the genus is quite different from that of any other graptolite. The form of the thecae and the great width of the branches seem to remove it from the Dicranograptidae." In the same description Hall remarks upon the resemblance of the thecae to those of *Isograptus* (*Didymograptus*) *caduceus*, and observes that concrescence of the branches of *D. caduceus* would result in the formation of a rhabdosome "somewhat similar" to *Oncograptus.*

In 1916 Harris figured the new genus *Cardiograptus* Harris and Keble (genotype, *C. morsus* H. & K.)—described by Harris in 1924—and referred to the series *Isograptus caduceus, Oncograptus, Cardiograptus* as "indicating a probable line of development". The suggested relationship was more fully discussed a few years later (Harris, 1933) in a paper on *Isograptus caduceus* and its allies, and Harris's views may be summarized in the following quotations: "Attention has already been directed to the tendency of *Isograptus caduceus* towards concrescence. . . . If the tendency towards an increase in the angle of divergence were carried to extremes the resulting rhabdosome would be biserial, at least proximally. . . . In *Oncograptus* we have a form initially biserial and then developing uniserial stipes. The biserial part is of varying length, sometimes so short that the specimen resembles an initially broad *Isograptus. Oncograptus* seems so closely related to *I. caduceus* that though its early stages are still obscure it seems justifiable to include it in the same family. . . . The failure of *Oncograptus* to develop its distally uniserial stipes would result in a wholly biserial form. *Cardiograptus* is such a form" (pp. 95–6). The series *Isograptus—Oncograptus—Cardiograptus* is definitely suggested (e.g. p. 88) as one line of development of biserial graptolites, although Harris acutely observes that if *Oncograptus* developed from *I. caduceus* "it was probably by a distinct break, as no intermediate forms are found in the Upper Castlemainian beds, where they might be expected."

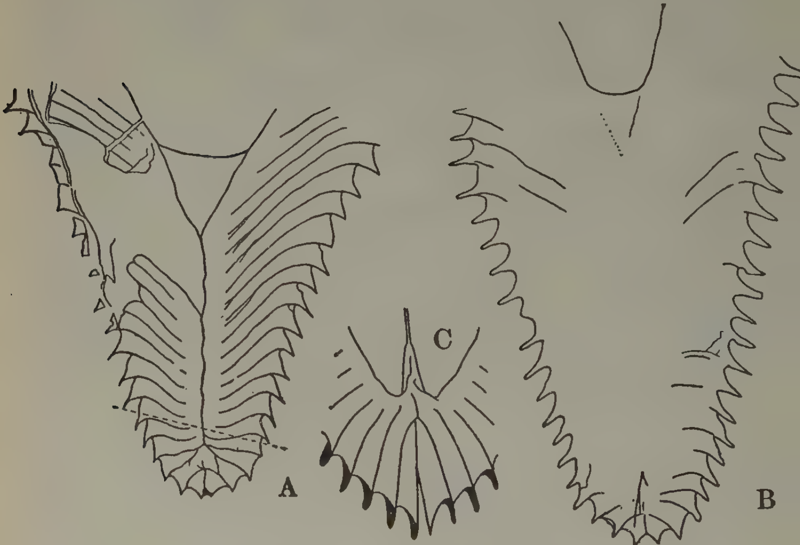
In investigating the possible lines of descent of biserial graptolites, therefore, the structure and relations of *Oncograptus* are clearly of considerable importance, but unfortunately the Australian material is all in such a state of preservation as to admit no detailed morphological study.

Material.

The material for the present investigation consisted of two specimens of *Oncograptus* from the El Paso Limestone (Canadian) of

Marathon, Texas, presented to the Sedgwick Museum in 1933 by Professor O. T. Jones. These specimens are preserved in semi-relief in an impure limestone; experiments with fragments of the matrix showed that the graptolite remains were too fragile to be freed by solution with hydrochloric acid, but there remained the possibility of serial sectioning by grinding. In only one example was the proximal end completely preserved, and this specimen is shown in Text-fig. 1A; sections were ground at 1/40 mm. interval, and selected sections from the series are shown in Text-fig. 2A and B. A wax model, in the form of an internal cast of the proximal end, was constructed from the complete series and is represented in Text-fig. 3.

In general characters and dimensions the American specimens seem most closely to resemble *Oncograptus upsilon* var. *biangulatus* (H. & K.), but it is only necessary in this place to assign them generic identification.



Text-fig. 1.—*Oncograptus* and *Isograptus.*

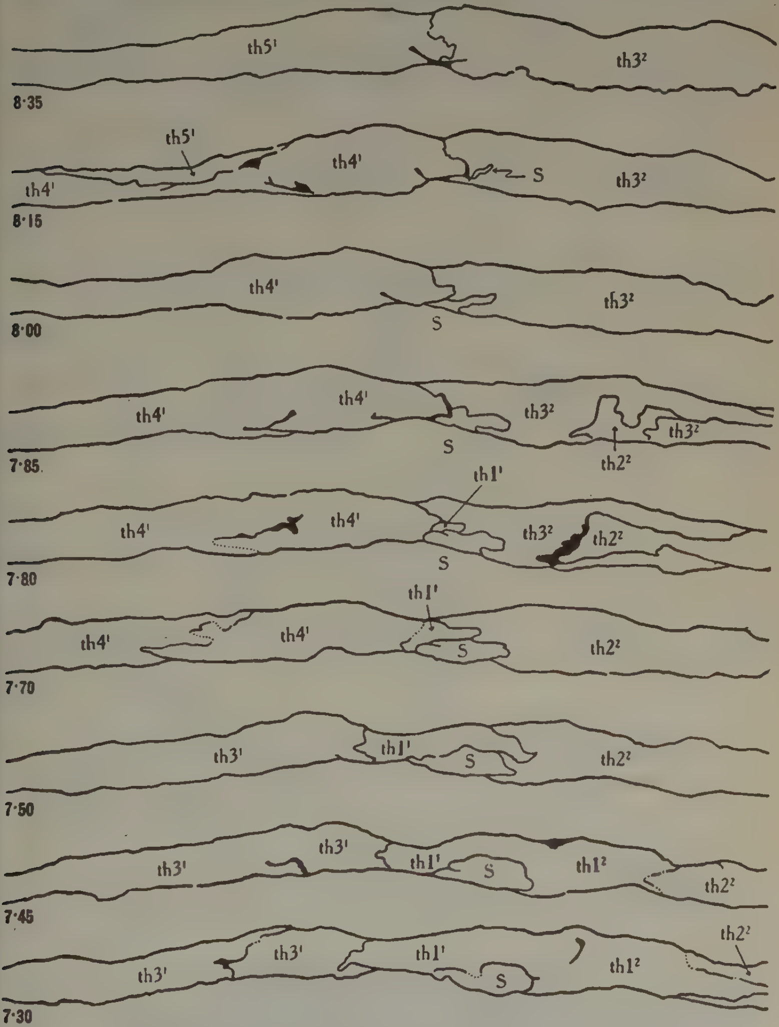
A. *Oncograptus* sp., Sedg. Mus., A. 8140. El Paso Limestone, Marathon, Texas; specimen used for sectioning, × 3½ approx. The portion ground away in the section series is shown by the broken line. Cf. Text-fig. 3.

B. *Oncograptus upsilon* T. S. Hall, Sedg. Mus., A. 8143. Darriwil series, near Woodend, Victoria; × 3½ approx. Proximal end with faint indications of sicula.

C. *Isograptus gibberulus* (Nicholson) [= *I. caduceus* (Salt.)], × 5 approx. Proximal end, showing mode of development, for comparison with *Oncograptus* (from *Arkiv. för Zool.*, 1932, Bd. 24A, No. 9, p. 24, fig. 1).

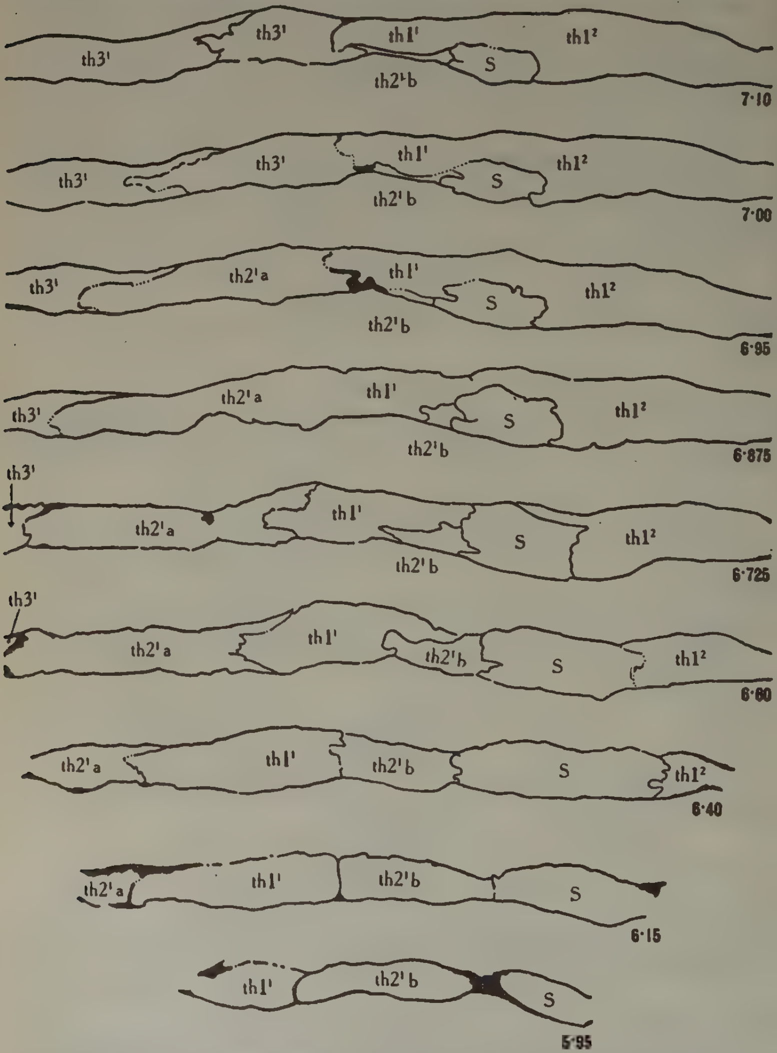
THE STRUCTURE AND RELATIONSHIPS OF ONCOGRAPTUS.

The length of the sicula is considerable (about 2·5 mm.), and this agrees with indications seen in one of the Australian specimens in the Sedgwick Museum (Text-fig. 1B), and it may be noted also that one of the published figures of *Cardiograptus* (Harris, 1926,



TEXT-FIG. 2A.—Serial sections through the proximal end of *Oncograptus* sp.; micrometer readings 8·35 — 7·30. Lateral portions of the two stipes, with hydrothecal apertures, omitted. × 30 approx. Sedg. Mus., A. 8140*b*.

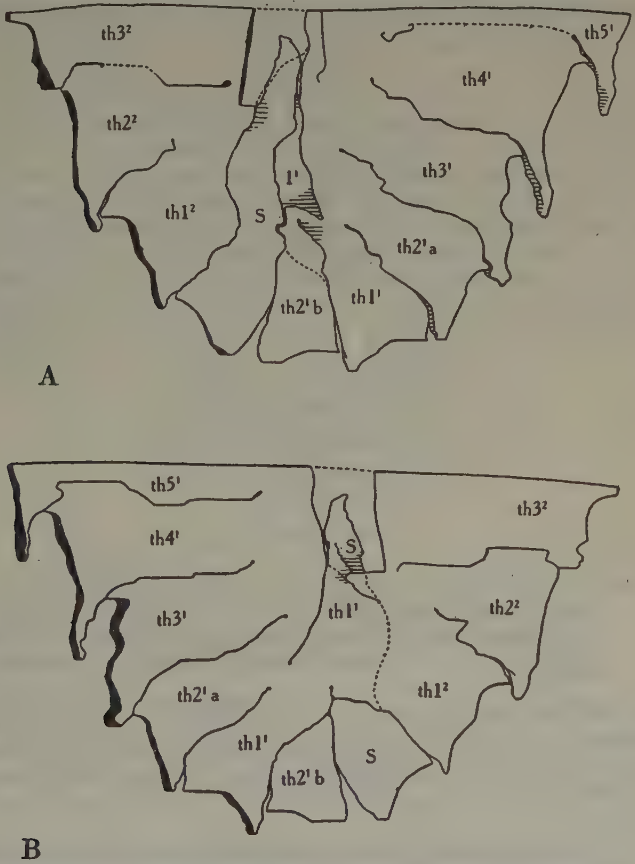
pl. 1, fig. 5) gives indications of a sicula of comparable length and an apparently similar conformation of the early thecae to that described below. From the sicula arises the initial bud (th1^1), very near its apex, and th1^1 grows down alongside the sicula for about one-half of its length before being separated from the sicula by the



TEXT-FIG. 2B.—Serial sections through the proximal end of *Oncograptus* sp.; micrometer readings 7·10 — 5·95. Lateral portions of the two stipes, with hydrothecal apertures, omitted, except in sections 6·40, 6·15, and 5·95. × 30 approx. Sedg. Mus., A. 8140*b*.

interposition of a theca to which reference is made below. Thl^2 is derived from thl^1 by a very broad crossing canal rather reminiscent of that of *Tetragraptus bigsbyi* and certain other Tetragraptids, but quite unlike that of *I. gibberulus* (Text-fig. 1c). From the base of thl^2 arises the secondary stipe, th2^2, th3^2, etc., but there is no second crossing canal as is present in the Isograptid type of development.

From thl^1 are produced two other thecae, labelled th2^{1}a th2^{1}b, arising at the same level from thl^1.[1] Of these one (th2^{1}a)



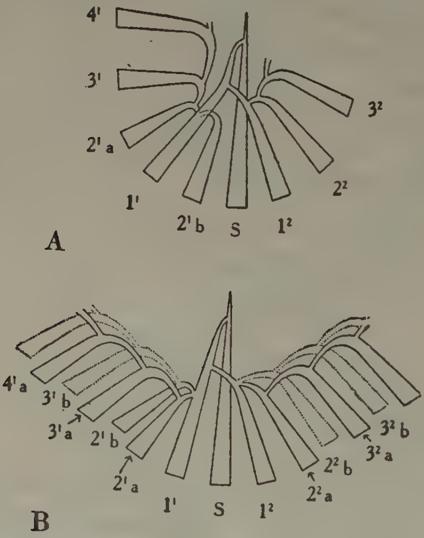
Text-fig. 3.—Wax model of the proximal end of *Oncograptus* sp., from serial sections. A, obverse; B, reverse aspect. × 15 approx. A portion of the common canal of the secondary stipe has been cut away in the model to expose the apex of the sicula and origin of thl^1. Cf. Text-fig. 2.

---

[1] Concerning the point of origin of the theca labelled th2^{1}b, the section series is not absolutely conclusive, and it would have been possible to derive it from

occupies the normal position on the primary stipe; it is very short and from its base is derived the remainder of the primary stipe, th3^1, th4^1, etc. The other, labelled th2^{1}b, is also short, and grows sharply round on the side opposite the crossing canal, taking up a position between the sicula and thl^1, and opening between their apertures. Viewed from the reverse side, there are thus two subsymmetrical apertures (S and th2^{1}b) enclosed between thl^1 and thl^2.

The rhabdosome is apparently related to a Tetragraptid, but the stipe reduction, complete on the side of thl^2, is incomplete on the side of thl^1 and one of the thecae of the fourth stipe, th2^{1}b, remains, twisted out of its normal position and incorporated in the compact proximal end between thl^1 and the sicula. The probable relations of this form to a Tetragraptid are shown in the thecal diagram, Text-fig. 4.



Text-fig. 4.—Thecal diagrams to show the structure of the proximal end in *Oncograptus* (A) and a hypothetical *Tetragraptus* ancestor (B). Portions of the Tetragraptid structure retained in *Oncograptus* are shown in continuous line; those portions lost in *Oncograptus* are indicated by dotted line.

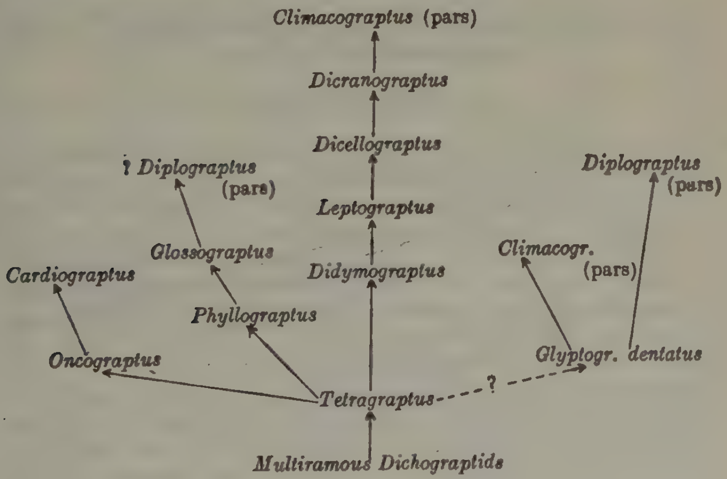
It will be noted that the development of the early thecae is "left-handed", when compared with the usual graptolite development. Whether the specimen is abnormal in this respect, or whether the

---

the sicula instead of from thl^1. Such an origin would, of course, be unique among graptolites as at present known. The interpretation adopted above is much more probable; as th2^{1}b, its presence and its subsymmetrical relation to th2^{1}a can be readily explained.

genus is characterized by a left-handed development, is impossible to say. Probably at this still comparatively early period of graptolite evolution the morphology of the proximal end had not acquired the stability which seems to characterize later genera and species, and it is possible that individual development might vary as it is known to do in *Dictyonema flabelliforme* and in *Clonograptus tenellus* and *Bryograptus hunnebergensis* (Stubblefield, 1929, p. 274). Again, for example, the better preserved specimens of *T. serra* may also show a left-handed development, but here, too, the preservation of most specimens is so poor that one cannot be certain whether the species was actually characterized by left-handed development or whether both left- and right-handed development may occur.

From the reconstructions of the proximal end, which it is now possible to give, it will be seen that *Oncograptus* can have no close relation to *Isograptus* (Text-fig. 1*c*), but is derived from a Tetragraptid in which the mode of development had not even progressed to the *minutus* stage of the Dichograptid type,[1] where $th2^1$ is produced from $th1^1$, opposite and approximately at the same level as $th1^2$. It hardly seems probable that a proximal end with the structure of *Oncograptus* could progress further towards the Diplograptid type of development and hence that *Cardiograptus* (assuming this to be its completely biserial descendant) could be an ancestor of any " normal " Diplograptids.



It is interesting to note in conclusion the dominance of four stiped forms as ancestors of biserial graptolites, and the comparative rarity of biserial forms descended from the two-stiped *Didymograptus*. A Tetragraptid has been suggested [1] as the most probable ancestor of the phylogenetically important *Glyptograptus dentatus* (the structure of which cannot readily be explained as a descendant of a Didymograptid); *Phyllograptus* is generally provisionally accepted as the ancestor of *Glossograptus* (Elles, 1922); and it now appears that *Oncograptus* (and presumably *Cardiograptus*) similarly have their origin in a four-stiped ancestor without the intervention of a *Didymograptus* stage. The scandent tendency seems to have been expressed more strongly and more rapidly in *Tetragraptus* s.l., and the scandent derivatives of *Didymograptus* as known at present evolved very much more slowly.

---

[1] *Arkiv. för Zoologi*, 1936, 28A, no. 17.

REFERENCES.

Elles, G. L., 1922. "The Graptolite Faunas of the British Isles," *Proc. Geol. Assoc.*, xxxiii, 168–200.

Hall, T. S., 1914. "Victorian Graptolites, Pt. IV," *Proc. Roy. Soc. Victoria*, xxvii, 104–118.

Harris, W. J., 1916. "The Palaeontological Sequence of the Lower Ordovician Rocks in the Castlemaine District," *Proc. Roy. Soc. Victoria*, xxix, 50–74.

—— 1924. "Victorian Graptolites (New Series), Pt. I," ibid., xxxvi, 92–106.

—— 1926. "Victorian Graptolites (New Series), Pt. II," ibid., xxxviii, 55–61.

—— 1933. "*Isograptus caduceus* and its allies in Victoria," ibid., xlvi, 79–114.

Stubblefield, C. J., 1929. "Notes on some Early British Graptolites," Geol. Mag., LXVI, 268–285.

Note on the Zone of *Anthraconauta phillipsi* in the Denbighshire Coalfield.

By Henry H. Simpson.

THE scarcity of shells in the Denbighshire Coalfield has been commented on by a number of observers,[1] and though numerous *Carbonicola* and *Naiadites* are to be found at certain horizons *Anthracomya* is exceedingly rare, particularly in the lower part of the Middle Measures. This lack of molluscan remains has made the zoning of the Coal Measures in Denbighshire a matter of considerable difficulty and only one occurrence of *A. phillipsi* (Williamson) has hitherto been recorded,[2] namely from the Coed-yr-allt Beds, the middle division of the Upper Coal Measures.

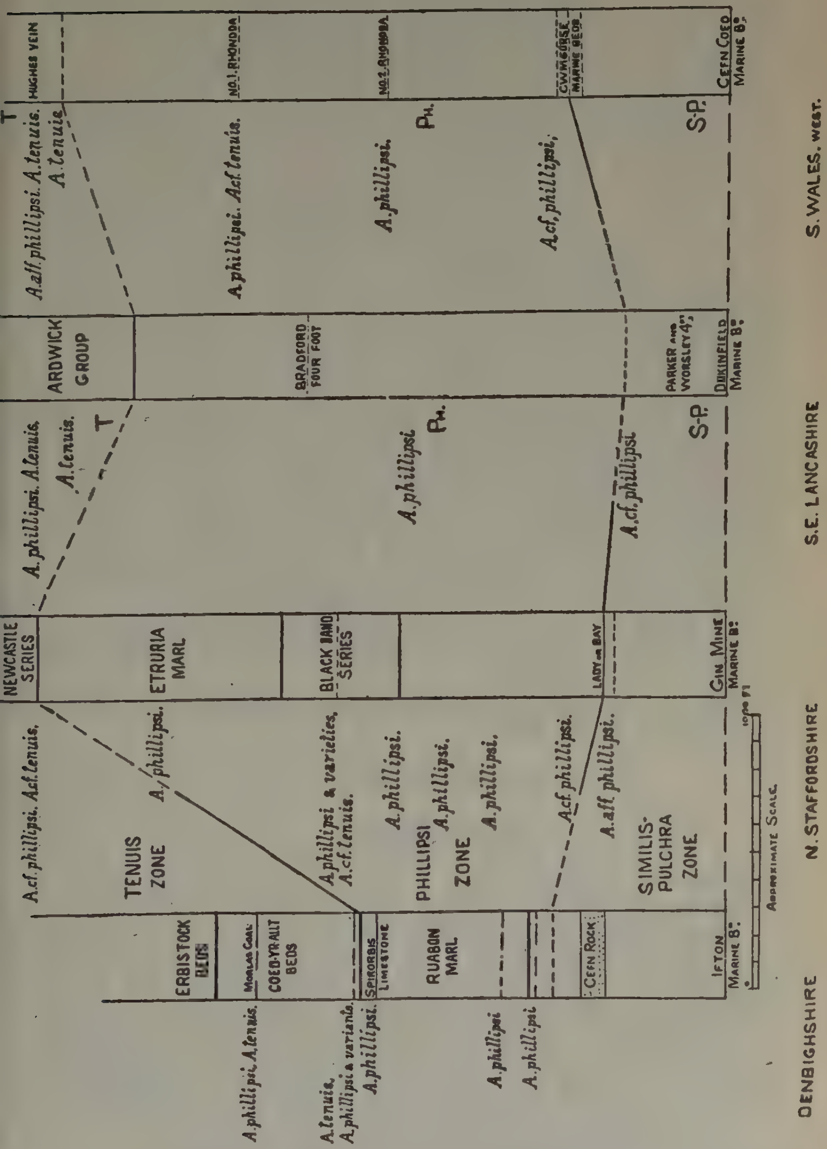
Recently the writer has found large crushed specimens from a bed of shale above a thin coal in the Middle Coal Measures, about 15 feet below the basement sandstone of the Ruabon Marl, the bottom of the Upper Coal Measures, and at about 700 feet above the horizon of the Ifton Marine Band.[3]

---

[1] "Geology of the Country around Wrexham, II," *Mem. Geol. Surv.*, 1928, p. 36.

[2] Ibid., p. 96.

[3] Geol. Mag., LXXII, 1935, 165.


DENBIGHSHIRE
N. STAFFORDSHIRE
S.E. LANCASHIRE
S. WALES, WEST.
ERBISTOCK BEDS
MORLAS COAL
COED-YR-ALLT BEDS
SPIRORBIS LIMESTONE
RUABON MARL
CEFN ROCK
IFTON MARINE Bᵈ
A. phillipsi. A. tenuis.
A. tenuis, A. phillipsi & varieties.
A. phillipsi.
A. phillipsi
A. phillipsi
TENUIS ZONE
PHILLIPSI ZONE
SIMILIS-PULCHRA ZONE
A. cf. phillipsi. A. cf. tenuis.
A. phillipsi.
A. phillipsi & varieties, A. cf. tenuis.
A. phillipsi.
A. phillipsi.
A. phillipsi.
A. cf. phillipsi.
A. aff. phillipsi.
A. aff. phillipsi.
Approximate Scale
0
1000 FT
NEWCASTLE SERIES
ETRURIA MARL
BLACK BAND SERIES
LADY or BAY
GIN MINE MARINE Bᵈ
A. phillipsi. A. tenuis.
A. tenuis.
T
A. phillipsi
Ph.
A. cf. phillipsi
S-P.
ARDWICK GROUP
BRADFORD FOUR FOOT
PARKER AND WORSLEY 4'
DUKINFIELD MARINE Bᵈ
A. aff. phillipsi. A. tenuis.
A. tenuis
T
A. phillipsi. A. cf. tenuis.
A. phillipsi.
Ph.
A. cf. phillipsi.
S-P.
HUGHES VEIN
NO. 1 RHONDDA
NO. 2 RHONDDA
CWMGORSE MARINE BEDS
CEFN COED MARINE Bᵈ

This is shown on the diagram, and the approximate distances from the bottom of the Phillipsi Zone to the Marine Band below are given for North Staffordshire,[1] South-East Lancashire,[2] and South Wales.[3] As the Denbighshire Coalfield is thinner than the others, it may be expected that eventually *A. phillipsi* will be found nearer the Ifton Marine Band than 700 feet, and the large size of the specimens also suggests the probability of smaller shells being discovered at a lower horizon.

The Ruabon Marl has hitherto yielded no molluscan remains but the writer has collected numerous *A. phillipsi* from a working in the Hafod-y-bwch Colliery, at about 85 feet from the bottom of the Marl, and from the Hafod Clay Pit at a horizon immediately above the Spirorbis Limestone, near the top of the Marl. He has also found in the overlying Coed-yr-allt Beds near Ruabon, about 10 feet above the base, beautifully preserved specimens of *Anthraconauta tenuis* (Davies and Trueman), *A. phillipsi*, and forms linking *A. tenuis* and *A. phillipsi*.

Higher up in the same series at a tip near Chirk formed of the waste from the working of the Morlas Coal over fifty years ago, *A. tenuis* occurs together with *A. phillipsi*. Elongated forms of *A. phillipsi* and *A. calcifera* (Hind) are apparently absent, but there is a plant bed containing a numerous and varied flora. Often in one piece of shale plants, shells, and plentiful *Spirorbis* sp. are all mixed up together. *Carbonicola* and *Naiadites* have not yet been found in the Tenuis or Phillipsi Zones of Denbighshire.

It is suggested that the change in conditions ushered in by the Coed-yr-allt Beds also marks the entry of *A. tenuis* and the upper limit of the Phillipsi zone.

I am indebted to Dr. W. B. Wright for assistance with the determination of the fossils.

REVIEWS.

Geologie von Europa, Band 2, Teil 2. By S. von Bubnoff. pp. 693–1134, with 9 folders and 44 text-figures. Borntraeger, Berlin, 1935. Price 32 RM. in paper cover.

The first part of the second volume of this colossal work dealt with the Palaeozoic foundation of extra-Alpine Europe (exclusive of Russia, to which volume 1 was devoted). In spite of some defects inevitable in the performance of so redoubtable a task by one man, the first volume and the first part of the second volume were widely welcomed as contributions to a veritable "new *Antlitz der Erde*". By masterly treatment the scattered Palaeozoic horsts, each one a nest of complications and difficulties, were synthesized so that the whole formed for the first time a unified tectonic and palaeogeographical picture. The performance deserved unstinted admiration and gratitude. The treatment of the British Palaeozoic rocks, it is true, seemed poor in comparison with the rest, and in relation to their importance in the history of the subject; but British geologists could afford to overlook that, for have we not our "Evans and Stubblefield"?

---

[1] Dix and Trueman, *Quart. Journ. Geol. Soc.*, lxxxvii, 1931, 203.

[2] "Geology of Manchester and the S.E. Lancashire Coalfield," *Mem. Geol. Surv.*, 1931, p. 152.

[3] Trueman, *Proc. S. Wales Inst. Engineers*, xlix, 1933, 94.

The second part, now issued, is entitled "*Die Entwicklung des Oberbaues*", and deals with the stratigraphy of the Permian, Mesozoic, and Tertiary rocks. The task of compressing so vast a mass of information into 440 pages has been performed probably as successfully as any one man could perform it. It is therefore no reflection on the author to say that the result strikes us as disappointing, and that in his small but brilliant book *Grundprobleme der Geologie* he rendered a greater service to geology than in this infinitely more laborious work. Such a task should in our opinion be planned by one master mind and then handed over to specialists for the writing, or at least the first drafting, of the individual chapters.

In turning from Part 1 to Part 2 we are conscious immediately of a descent from synthesis to compilation. There are only two brief but very interesting chapters (twelve pages in all) on such general matters as "Die Wendezeit im Perm" and "Die Epirogenese Westeuropas". But elsewhere in the book the author makes some interesting generalizations. One is the contrast which he points out between the epeirogenesis of the Permo-Trias and the Jurassic: the Zechstein and Muschelkalk showing slow continuous deposition unbroken by smaller cycles; the Jurassic showing innumerable small cycles and zones, eloquent of increased tectonic activity. At the beginning of the Jurassic, too, the trend of the troughs of subsidence began to diverge more strongly from the direction of the grain in the Variscan foundation (p. 827). Another interesting point (p. 785) is the author's conclusion that the Rhaetic Tethyan fauna, since it could not have reached England by way of Northern France and probably did not do so by way of Germany, may have migrated hither up the Atlantic. Professor von Bubnoff is led to this conclusion by the close resemblance between the Rhaetics of England and the South of France, and by recent work by Jüngst, who claims to show that in central Germany the Rhaetic sea advanced away from Britain, towards the south. The suggestion gains in significance from the interesting and heretical opinion that the Atlantic and other oceans existed already in Jurassic times, recently expressed by Dr. L. F. Spath as a result of his revision of the Cephalopoda of Cutch. These are views which, if they eventually prove correct, will obviously have important repercussions on world-theories such as continental drift.

Some general criticisms of Part 2 occur inevitably to the English reader. The first is that all the stratigraphical and zonal tables throughout the book are upside down. This is a logical result of starting all descriptions from the bottom; but such logic is a bad master. It is with relief that we turn to the folding tables at the end, which are the right way up. The second criticism is that the scores of pages devoted to lists of fossils in small italic type might have been omitted, thus lightening and cheapening the book by nearly a half. At least they might have been printed in a supplement, which anyone who wished could buy separately. Such lists of fossils are unreadable and therefore can only be inserted for reference. But if they are for reference they should be printed in column and in some definite order, either systematic or alphabetical, and should not be interlarded with the text. At the best the value of such lists is questionable unless they are compiled by specialists. The reviewer can only answer for a few of them with authority, and he must testify that those few are inaccurate and misleading. It is to be hoped that palaeontological solecisms as bad as *Prionodoceras dichotomum* (p. 871) are rare.

The polemical questions of stratigraphical terminology have on the whole been skilfully handled, and there is an admirable catholicism in the choice of stage and formation names. Those who do not agree can at least understand, for alternatives are given. Dr. Spath must read with some discomfiture the immortalization of his subsequently disavowed palaeontological Ages devised for the Cretaceous on the lines of those introduced by Buckman for the Jurassic. Professor von Bubnoff seems to have overlooked the disavowal and has relentlessly inscribed them all—Gauthiericeratan, Prionotropidan, Stantonoceratan and the rest, in unlovely cadence.[1]

Palaeogeographical maps are pleasingly abundant, but, in respect of at least the British portion, often out of date. That on p. 904 embodies an especially hard-dying error—the extension of the Portlandian sea over Yorkshire; and this despite the fact that in the text (p. 932) the author shows himself aware that this Speeton Clay sea has been shown to be Lower Cretaceous. But perhaps the anomaly is accounted for by the author's far-too-wide interpretation of the "Portland", which he extends down to the base of the Middle Kimeridge Clay (base of the *Gravesia* zones) following Salfeld and most other Continental authors. Salfeld's able but rapidly ageing paper is too often followed in the Jurassic portion of this book, and the subsequent corrections are too often ignored. There is another misleading statement about the Lower

---

[1] "In the circumstances it is best to drop these age-terms, for stages and zones are essentially time-terms, i.e., the deposits they include are merely local incidentals and there is no need for a separate nomenclature" (Spath, 1933, *Pal. Indica*, N.S. vol. ix, Mem. 2, p. 870). It is ironical that Buckman's Ages of the Jurassic, which were never repudiated by their author, find no place in Professor von Bubnoff's work.

Cretaceous on p. 929. The "strong erosion" and earth-movements which caused part of the Lower Cretaceous to overstep all rocks down to the Oxford Clay in England was not pre-Cretaceous (pre-Wealden), but pre- or early-Aptian. The Wealden is folded in conformity with the Jurassic and overstepped by the Aptian.

Finally, as in Part 1, the bibliographies are slovenly, and it must unfortunately be said that the selection of items does not seem to have been governed by complete international impartiality. It certainly could not be maintained, as implied by the Tertiary bibliography, that out of the 153 most important contributions to the knowledge of the Tertiaries of extra-Alpine Europe only one is in the English language, even though that one is one of Mr. A. Wrigley's valuable papers. In the Cretaceous chapter we fare better, with 19 references out of 178; but from the single entry under the name of Rowe we should gather that his work was published in the form of a book, since no reference is given; and the appended dates exclude the final and perhaps the most important of his series of papers, that on the White Chalk of the Isle of Wight (1908). Both here and in the discussion of Chalk zoning in the text, Rowe's world-famous work on the Micrasters is not mentioned. Purely as an example, it may be mentioned that the present reviewer finds himself honoured by being referred to by three different dates in the text, while only one work is listed in the bibliography, and that under the wrong title and with the wrong place of publication.

We are promised in Part 3 a summary of the Quaternary period and, above all, an account of the present-day structure of extra-Alpine Europe, which shall trace its evolution as the resultant of the interplay between the mosaic foundation of Palaeozoic rocks and the Mesozoic and Tertiary superstructure. Perhaps there the rather dry bones of Part 2 will take on flesh.

W. J. A.

REGIONAL PETROLOGY OF THE SOUTHERN NORTH SEA. By J. A. BAAK. pp. 127. H. Veenman en Zonen, Wageningen. N.D.

IN this thesis for the degree of Doctor of Science in the University of Leiden, the author gives an account of his own research work on the petrography of the deposits now forming the floor of the North Sea, and of many deposits off the surrounding coasts, preceded by a useful summary of previous work. He delimits five principal petrographical provinces, some clearly defined, and some overlapping. There is also included a discussion of the geological history of the area in Quaternary times, with special reference to the date of opening of the Straits of Dover and the former courses of the Rhine. Dr. Baak does not believe that this river ran through Norfolk in the Riss period. The clearest statement of the results obtained is to be found in the Dutch summary at the end, where the whole thing is reduced to about four pages, whereas the English text is very diffuse. Since the different provinces distinguished are called Group A, Group H, and so on, it is hardly possible here to state their characteristics; this would occupy far too much space, but it may be noted that the distinctive minerals, hornblende, augite, saussurite, garnet, and so on, supposed to have been largely contributed by the Rhine, differ widely from those dominant in earlier deposits. One of the chief points that strikes the reader of this memoir is the enormous change introduced into the heavy mineral assemblages of the area by the advent of the glacial period in contrast to the deposits of the Mesozoic, or even of the Tertiary. Quite lately, the present writer, after many years of work on Jurassic and Cretaceous sandstones happened to pick up casually an old slide of a concentrate from a beach sand of the Yorkshire coast. The difference was astounding. After the delicate work with high-power objectives and refined optical methods on the tiny grains of the Jurassic sandstones, the modern concentrate seemed to consist of great lumps of minerals of startling colours and strangely angular forms. And furthermore the lists of minerals in the two sets were for all practical purposes entirely different. The dominant minerals in the modern sands are rarities or do not occur at all in the Jurassics.

R. H. R.

COPPER RESOURCES OF THE WORLD. In two volumes. pp. 855, with 41 plates and 140 text-figures. XVI International Congress. Washington, 1935.

IT is quite impossible to review a work of this kind in the ordinary sense of the word. It consists of a large number of monographs by the best available authorities on all branches of the subject, and its publication has been supervised by a highly competent committee; anything of the nature of criticism would therefore be almost an impertinence, since no individual could presume to dogmatize on more than a very limited portion of the scope of the book, and in any case to do so would be invidious and unfair.

The first section, the Introduction, gives a very interesting summary of the development of the copper industry, mainly during the last hundred years, and in this due acknowledgment is made of the fact that England stood first as a producer for the first half of the nineteenth century (England, as usual in non-British books, here really means the British Isles: Wales played an important part). From 1850 to 1880, Chile came first. The United States, starting seriously about 1840, in the next forty years advanced to first place, and has remained so ever since. Consequently, it is not surprising to find that, apart from introductory and historical matter the whole of the first volume is devoted to North America. Taking into account the considerable production from countries other than the United States, this is not so disproportionate as it appears at first sight.

Turning now to Volume II, it may be noted that contributions by non-English-speaking authors have very wisely been allowed to remain in the languages in which they were written; French, German, Spanish, and Italian. A translation, however good, always misses something of the spirit of the original. If it is permissible to pick out individual contributions for special mention, it may perhaps be noted that readers in the eastern hemisphere will turn with particular interest to the sections on the copper mines of the Belgian Congo and Northern Rhodesia, which is by far the most important development of recent years. Hitherto it has been very difficult to find an authoritative account of this remarkable region in a condensed form, although there is a large amount of scattered literature, often not very accessible.

It is interesting to note that this volume contains two independent accounts of the cupriferous pyrite deposits of the Huelva district, a short one in Spanish compiled by the officers of the Instituto Geológico y Minero de España, and a somewhat longer one in English by Professor Arnold Heim, of Zürich; both of these come down strongly in favour of the theory of direct intrusion of sulphide magma, with limited replacement near the margins only, as against the idea of wholesale replacement by solutions, which has lately found favour in some quarters.

This great work will certainly take a foremost place among the publications on economic geology which we owe to the labours of the International Geological Congress at its long series of meetings in all parts of the world.

R. H. R.

REPORTS AND PROCEEDINGS.

Mineralogical Society.

26th *March*, 1936.

Professor C. Gilbert Cullis exhibited villiaumite from the Los Islands, Sierra Leone; and pseudogaylussite dredged from the Clyde, from the collection of the late Professor J. W. Gregory.

(1) "Two new Meteoric Stones from South Australia—Lake Labyrinth and Kappakoola." By Dr. L. J. Spencer.

These two meteorites have recently been recovered by Mr. R. Bedford of the Kyancutta Museum, South Australia. The first was seen to fall and was located by a half-caste aboriginal in 1924 at a spot (30° 20′S., 134° 45′E.) about 27 miles north-west of Lake Labyrinth. Broken and weathered fragments with a total weight of 57 lb. were collected in 1934, and the original weight of the mass is estimated at 75 lb. It is a light grey chondritic stone with very little metallic nickel-iron and troilite. The second meteorite was found in 1929 on a sand-hill at about 33° 20′S., 135° 30′E. in the hundred of Kappakoola, county Le Hunte, Eyre Peninsula. It is a small, completely crusted stone weighing 392·5 grams and of unusual shape, having the form of a right triangular prism with flat base and domed top It is a minutely brecciated olivine-chondrite with a medium amount of nickel-iron and some troilite. A list is given of thirteen South Australian meteorites, for some of which information is not yet available.

(2) Some Malvernian Hornblendes: their Genetic Relationships." By Professor A. Brammall and Mr. J. G. C. Leech.

Analyses of twelve hornblendes from "appinitic" types, together with optical, spectroscopic, and assay data, confirm field evidence that the rocks themselves are syntectics of (*a*) hornblendite-pyroxenite terms and/or (*b*) amphibolites, epidiorites, etc., with (*c*) granitic, plagioclasic, and other magmatic fluids (including emanations)—acting singly, successively, or in oscillation. In any one rock-type the amphibole is polyvarietal: e.g. in the Hollybush "gabbro-diorite" (yielding water-worn zircons, etc.), tremolite—actinolite—green hornblende—blue-green hornblende. The $(OH) = 2$ of the standard X-ray amphibole constitution is not sustained: n varies between 1·2 and 2·9 independently of the other groups and of the Al–Si relationship.

(3) "The Effects of Heat on the Optical Orientation of Plagioclase Felspars." By Dr. C. T. Barber (communicated by Professor C. E. Tilley).

In 1931, T. W. Barth described a change of 6° in the optical orientation of labradorite due to heat treatment at 1000° C. for 300 hours. The experiments now described were undertaken to ascertain the amount and variability, both in direction and magnitude, of the displacement of the indicatrix under the influence of heat. The author has been unable to reproduce Barth's results, and as a result of twelve experiments on albite, andesine, labradorite, and anorthite, concludes that the change in the optical orientation is so slight as not to permit of accurate determination by the Fedoroff method.

(4) "X-ray Studies on Psilomelane, Pyrolusite, and Hollandite." By Mr. George Vaux.

Specimens of polianite originally described by Dana and Penfield from Platten, Bohemia, are identical with pyrolusite (Haidinger, 1827). Therefore the name pyrolusite should be used both for fibrous specimens and for those exhibiting well-formed tetragonal crystals. Botryoidal formations encrusted with minute crystals of so-called "polianite" from Schneeberg, Saxony, contain 16 per cent BaO and have the same chemical composition as material from the same locality originally described and named psilomelane by Haidinger. Polished sections and X-ray photographs show that the compact psilomelane and the minute crystals from Schneeberg have the same crystal structure. The unit-cell dimensions of psilomelane, hollandite, manganite, etc., are found to be simply related to those of pyrolusite.

(5) "Biographical Notices of Mineralogists recently deceased." (Sixth series.) By Dr. L. J. Spencer.

Thirty-five obituaries with sixteen portraits are presented for the period 1933–6. Ages range from 57 to 89 with an average of 71·4 years. In the six numbers of this series since 1919 there has been a gradual and steady increase in the average age from 63·6 to 71·4 years.

CORRESPONDENCE.

THE COAL MEASURES OF SCOTLAND.

Sir,—I should like to be allowed to draw attention to one of the conclusions reached by Dr. John Weir and Mr. Duncan Leitch in their most valuable paper on the non-marine Lamellibranchs of the Coal Measures of Scotland (*Trans. Roy. Soc. Edin.*, lviii, 1936, 697–752). They point out that the evidence which they have collected indicates that the strata which there lie between the Mill (Auchingane) Coal of the Central Coalfield and the base of the Coal Measures are "homotaxially equivalent to a small uppermost fraction of the Lower Coal Measures of the North of England". This confirms the view expressed by previous workers on the shells (Dix, Pringle, and Trueman, *The Naturalist*, 1930, 321–6).

This conclusion is of great importance in relation to the problem of the Lanarkian Series. As defined by Kidston this series originally included a great thickness of the Scottish Coal Measures above the Mill Coal, but in England he placed within it only the Millstone Grit and Lower Coal Measures; recently it has been suggested that the Lanarkian in Scotland should be restricted to that part of the Coal Measures which is equivalent to the Lower Coal Measures of England, that is, to the strata below the Mill Coal.

Dr. Weir and Mr. Leitch point out, however, that if this course is followed the Lanarkian is practically excluded from Lanarkshire. It would surely be undesirable to define the Lanarkian as "that part of the Coal Measures which are almost unrepresented in Lanark", but this seems to be the only basis on which the term can survive.

Is it too much to hope that with this clear evidence of its unsuitability the unfortunate term Lanarkian may now be allowed to lapse?

A. E. Trueman.

25th March, 1936.

RIVER PROFILES AND DENUDATION CHRONOLOGY.

Sir,—As a former student of Professor Baulig, I was naturally most interested to read Dr. Wooldridge's paper on the above subject published in your January number. The subject is one of extreme importance, and it was most gratifying to realize that such keen interest has been awakened in England on this matter. I should be pleased if you would allow me to make one or two suggestions with regard to points raised by Dr. Wooldridge:—

(1) With regard to the terms "profile" and "graded river". When drawn on a very small scale the profile of a main stream that has reached grade frequently appears very smooth, so much so, indeed, that attempts have been made to establish mathematical

formulae for determining such curves. Hence the supposition that a graded river shows a curve of gradually decreasing slope.

Now in the case of graded streams (i.e. ones in which the water is flowing along a continuous alluvial bed that is being neither cut into nor sensibly aggraded) it is very frequently observed that a profile drawn on a large scale is by no means a curve of gradually decreasing slope. Such a smooth curve can obtain only when the water mass increases gradually downstream, the load at the same time increasing gradually, without going beyond a certain limit, and gradually diminishing in size, i.e. in calibre. As Baulig points out, this state of affairs is but rarely realized in nature, and as a consequence profile breaks in the main stream may occur owing to the confluence of an important tributary, with slope reduction if the tributary is as laden, or less laden, than the main stream, and slope increase if the tributary is much more laden than the main stream. In other words, breaks of slope are quite to be expected in a graded stream, and may have nothing whatsoever to do with waves of retrogressive erosion.

(2) It is hazardous to attempt to determine warping or eustatic shifts from examination of rivers *ungraded* before the change took place. If down-warping took place in a, say, seaward direction, then incision would be (for graded streams) at a maximum at the seaward end, since there the increase of slope would be greatest. However, still considering streams graded before the warping, if for a part of its course the stream flows away from the coast (i.e. if it has a somewhat circuitous course) then the downwarp will decrease the slope of this part of the graded river, and the river will begin to *aggrade* its bed. Where the river flows parallel to the axis of downwarp, there will be a tendency to lateral shift in a seaward direction. It is therefore not strictly correct to say that if the whole of a stream course were tilted by differential movements, it would become simultaneously out of adjustment at all points on its course and *renewed downcutting would begin throughout.*

In conclusion, may I recall the attention of your readers to Baulig's paper, "La Notion de Profil d'Equilibre," published in the Compte Rendu du Congrès Intern. de Géographie, Cairo, 1925.

JOHN HANSON-LOWE.

NATIONAL RESEARCH INSTITUTE OF GEOLOGY,
PEI-CHI-KO,
NANKING, CHINA.
13th February, 1936.

THE

GEOLOGICAL MAGAZINE

VOLUME LXXIII.

No. VII.—JULY, 1936.

ORIGINAL ARTICLES.

Cephalopods and a Beatricea from Akpatok Island.

By the late AUG. F. FOERSTE and IAN H. COX.

(PLATE IV.)

I. INTRODUCTION AND CORRELATION.

THE fossils collected from Akpatok Island, Ungava Bay, by Bell (1899) were studied by Whiteaves (1899). The latter author stated that of these "eleven had previously been found in the Manitoba Trenton, and nine are species that are common (in this Manitoba Trenton) at East Selkirk and Lower Fort Garry. The two fossils of which by far the most specimens were collected (about thirty of each species) are *Streptelasma robustum* and *Cyrtoceras manitobense*. The former is a rather large rugose coral, the types of which are from the Red River Valley in Manitoba." The collection made from the same island by Cox in 1931 (Oxford Hudson Straits Expedition), however, showed that *S. robustum* is very rare, while *S. arcticum* Wilson, a species not unlike it superficially, is extremely common. It is very possible that Whiteaves regarded specimens of *S. arcticum* as belonging to his own species, but, Bell's collection being lost, it is not possible to verify this.

For the strata included by Whiteaves in his "Manitoba Trenton" Foerste (1929) proposed the name Red River formation. In ascending order this formation includes the Dog Head limestone, the Cat Head limestone, and the Selkirk limestone. It is overlain by the Stony Mountain formation of Richmond age, and is underlain by the Winnipeg sandstone, which may be the initial stage of the Red River formation.

Streptelasma robustum is found in both the Dog Head and the Selkirk members of the Red River formation. *Cyrtoceras manitobense* is known only from the Dog Head member (Foerste, 1929). This species was used by Foerste (1924) as the genotype of *Westonoceras*.

Among the other species which Whiteaves identified from Akpatok Island are *Receptaculites oweni* and *Calapoecia canadensis*. Of these the former is listed from both the Dog Head and Selkirk members, while the latter is listed not only from those two divisions but also from the overlying Stony Mountain formation (Dowling, 1900, 69, 79, 81 f.). It is significant that this Stony Mountain formation was correlated by Twenhofel (1928, 66–7), with zones 3, 4, and 5 of his Vauréal formation, a member of the Richmond group exposed on Anticosti Island.

Several of the fossils collected by Cox from Akpatok Island appear to confirm the correlation of the greater part of the strata there exposed with the Red River formation. These are: (1) an unidentified species of *Westonoceras*, found at a height of 270 feet; (2) a living chamber, differing from that of typical *Shamattawaceras ascoceroides* Foerste and Savage (1927) only in its larger size, found at 450 feet in the limestones; (3) a typical specimen of *Huronia septata* Parks (Foerste and Savage, 1927), from 650 feet; and (4) the stromatoporoid *Beatricea undulata* Billings, also from a height of 650 feet.

Now in the province of Manitoba these four fossils occur in approximately the same sequence. In the Hudson Bay area *Westonoceras nelsonense* (Foerste, 1924, 223) is found in the Nelson River formation; *Shamattawaceras ascoceroides* is known only from horizon 1 of the Shamattawa limestone (Foerste and Savage, 1927); typical *Huronia septata* is recorded only from the overlying horizon 2 of the same limestone, though a closely related form occurs already in horizon 1. Although *Beatricea undulata* is not present in the Hudson Bay area, it occurs in southern Manitoba in the Stony Mountain formation, which there overlies the typical Red River formation, with which the Nelson River-Shamattawa sequence is correlated (Foerste, 1924).

In southern Manitoba *Westonoceras manitobense* occurs in the lower, or Dog Head, member of the Red River formation. In southern Minnesota *Westonoceras minnesotense* occurs in the Stewartville formation, directly over the Prosser member of the Trenton.

On Anticosti Island *Beatricea* is known only from the Vauréal and Ellis Bay formations, and not from the underlying English Head member of the Richmond (Twenhofel, 1928). Similarly *Beatricea* is known in Kentucky and Indiana only from the Liberty, Whitewater, and Elkhorn members of the Richmond group, and not in the underlying Waynesville or Arnheim members of that group.

The cephalopod fauna of Akpatok Island, then, suggests the following tentative correlations: The *Westonoceras* horizon on the Island apparently corresponds to part of the Nelson River formation of the Hudson Bay area; the *Shamattawaceras* and *Huronia* horizons apparently to the Shamattawa formation of the same area; and the *Beatricea* horizon probably is of Richmond age.

But before these conclusions are accepted with confidence much further information is needed. In the first place it is by no means certain that *Westonoceras* is confined to the basal part of the Red

River formation and its equivalents elsewhere. For instance, the stratigraphical equivalence of the horizon at which *Westonoceras deckeri* Foerste is found in the vicinity of Bromide, in south-central Oklahoma, is not known, beyond the fact that it occurs in the upper part of the Viola formation. And it is possible that *Orthoceras ortoni* Meek from the middle part of the Eden formation of south-western Ohio may be a *Westonoceras.*

Secondly, more information about the structure of *Shamattawaceras* is needed. Apparently this genus is closely related to *Probillingsites*, differing chiefly in its greater ventral flattening, and in the small downward curvature of the sutures of its septa on this ventral side.

Thirdly, the *Huronia* from Akpatok Island and the Hudson Bay area is so similar to some specimens occurring in the Silurian that it is probable that forms closely similar to *Huronia septata* must have existed somewhere in the world in the Ordovician later than the time at which the Shamattawa formation was deposited.

Lastly, the occurrence of both *Huronia septata* and of *Beatricea undulata* at the 650 ft. horizon requires further investigation, considering our former knowledge of their vertical distribution in the Manitoba area at very distinct horizons. Unfortunately it is at about this horizon that collection from the Akpatok limestones is the most difficult, on account of the abundance of frost-produced limestone fragments. Probably the best locality for collection at these levels would be somewhere in the north-east of the Island.

The problems attendant on the recurrence of faunas in the Middle and Upper Ordovician in America have made it essential that the individual members of each fauna should be studied with very great exactness if satisfactory correlations are to be made. The brachiopod fauna of Akpatok Island has not yet been the subject of detailed study, but it might not be out of place here to review the evidence as to horizon afforded by the other groups of fossils.

It has been shown above that the cephalopods indicate the possibility of correlation of the lower part of the Akpatok section with the Nelson River and Shamattawa formations of the Hudson Bay area, and the presence of *Beatricea undulata* at 650 feet suggests a Richmond age for the strata exposed there. Now the trilobite *Megalaspis beckeri* Slocom was found at 650 feet, and, being a form described from the Maquoketa Shale of Iowa, supports the evidence of Richmond age supplied by *B. undulata.* But with regard to the low horizons, *Ceraurinus icarus* (Bill.) is found on the Island at sea-level and 450 feet. This is usually considered a Richmond fossil. It is found on Anticosti Island (English Head, Vauréal, and Ellis Bay; Twenhofel, 1928, 334), in the Maquoketa Shale (Slocom, 1914, 227) and the Stony Mountain formation. But Billings's type of this species has been lost, and the original description and figures are, perhaps, too summary for modern requirements (Cox, 1933,[3] 367–8). Another fossil from the lower beds is *Pterygometopus fredricki* Slocom (350–400 feet), which is otherwise only recorded from the

Maquoketa Shale (Cox, 1933,[3] 370–1). A specimen identified as *Isotelus iowensis* (Owen) was found at sea-level on the Island. This is another Maquoketa species; but there are some differences between the Akpatok specimen and those from Iowa (Cox, 1933,[3] 360). The trilobite fauna of Akpatok Island comes most nearly to that of the Cape Calhoun beds of North-West Greenland (Troedsson, 1928), but at the time of writing there are reasons for refraining from correlating back to America from this fauna.

The coral fauna consists of species that might be of Richmond age or earlier. But such a diagnostically Richmond form as *Streptelasma rusticum* (Bill.) is absent. The significance of *S. robustum* Whit. (found at sea-level) has already been discussed. Specimens of *Calapoecia*, which are found from sea-level to 450 feet, have been made the subject of a detailed study (Cox, 1936). Some are identical with the type of *C. anticostiensis* Bill. from the Ellis Bay formation of Anticosti Island, with which Twenhofel (1928, 130) found specimens from the English Head and Vauréal formations identical. But there are others very similar to the more primitive forms, hitherto called *C. canadensis* Bill., which have no coenenchyme. The latter, while occurring as early as the Black River, is also found in undoubted Richmond strata. Both the Nelson River and Shamattawa formations contain *Calapoecia* cf. *canadensis* (Savage and van Tuyl, 1919, 341–2). This identification gives one no idea of the form of *Calapoecia* found there, for until the present revision of the genus the species were unrecognizable from the confusion of literature.

The *Plectambonites* (sens lat.), which give a comparison with British strata, cannot be used to correlate with American horizons at present. They are probably more advanced than the typical *S. sericea*, derived from the middle part of the Lower Bala, and certainly not as advanced as forms from the Upper Bala (Jones, in Cox, 1933,[1] 3).

II. DESCRIPTION OF SPECIES.

(By the late A. F. Foerste.)

Endoceras coxi new species.

Text-figs. 3, 4.

Holotype: (A 6837).[1]

Conch 95 mm. long, its diameter at the second camera from its base being 62·5 mm. Four camerae occupy a length of 69 mm., indicating 3·6 camerae in a length equal to the diameter of the conch. The sutures of the septa are directly transverse ventrally or slant but slightly downward in a ventral direction. The concavity of the septa is 15 mm. The siphuncle is 29 mm. in diameter, and its distance from the ventral wall of the conch is 8 mm. The septal necks are nearly straight or cylindrical. Only the cast of the interior of the conch is preserved and the surface of this cast is smooth.

---

[1] The numbers in brackets refer to the catalogue of the Sedgwick Museum, Cambridge where the specimens have been deposited.

Occurrence.—Akpatok Island, at an elevation of 450 feet.

Remarks.—This specimen is characterized by the relatively small number of its camerae in a length equal to the diameter of the conch, by its fairly large siphuncle, and by the conspicuous distance of the latter from the ventral wall of the conch. The rate of enlargement of the conch cannot be determined.

Endoceras sp.

(A 6844.)

Conch 126 mm. long, its lateral diameter enlarging from 45 mm. at its base to 53 mm. at its top. Dorsoventrally it is crushed so that its diameter at mid-length is 37 mm., the siphuncle being almost in contact with the wall of the conch on the crushed side of the latter. At mid-length three camerae have a total length of 44 mm., indicating about 3·5 camerae in a length equal to the lateral diameter of the conch. The sutures of the septa are distorted by pressure, but appear to have been directly transverse originally. At the base of the specimen, at a lateral diameter of 48 mm., the diameter of the siphuncle is 20 mm. The distance of this siphuncle from the more distant wall of the conch is 14 mm. The specimen is a cast of the interior of the conch, and the surface of this cast is smooth.

Occurrence.—Akpatok Island, at an elevation of 450 feet.

Remarks.—This specimen resembles the preceding one in the number of its camerae in a length equalling the diameter of the conch and in the diameter of its siphuncle, but the original form of the cross-section of the conch is not known definitely. If this cross-section was circular then the location of the siphuncle may have been subcentral.

Endoceras sp.

(A 6836.)

The original length of this specimen was about 70 mm. The conch has been compressed obliquely, so that its present maximum diameter at an angle of about 45 degrees to the dorsoventral plane of symmetry is 44 mm., while its lateral diameter is reduced to 38·5 mm. The distance between the septum at the top of the specimen and that near its base was about 50 mm. There is a trace of septation along the vertical dorsoventral section of the upper half of the specimen, suggesting the presence of camerae about 16 mm. long. This indicates three camerae in a length of 50 mm., or about 2·65 camerae in a length equal to the maximum diameter. The suture of the septum at the base of the specimen is directly transverse. The concavity of this septum is about 13 mm. The siphuncle here has a diameter of 24 mm., and it is estimated that its original distance from the ventral wall of the conch was about 3 or 3·5 mm., indicating a total diameter of 46 mm. for the conch at this point. The direction of the dorsoventral plane may be determined by noting the highest and lowest point reached by the septal annulation near the lower end of the specimen. The specimen is a cast of the interior of the conch and its surface apparently was smooth.

Occurrence.—Akpatok Island, at an elevation of 450 feet.

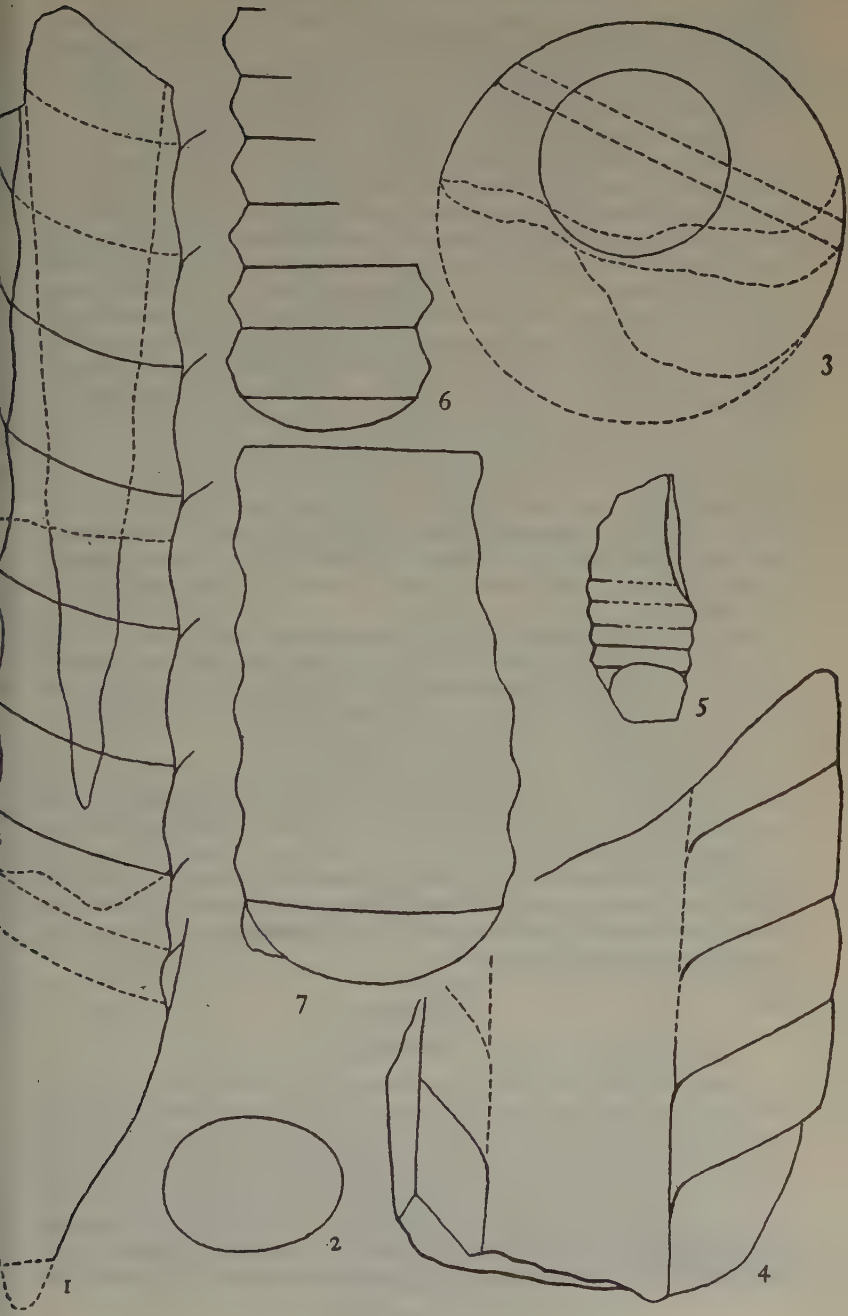
Remarks.—Compared with the two preceding specimens the camerae are relatively longer compared with the diameter of the conch, the siphuncle is a little larger, and its distance from the ventral wall of the conch is distinctly less. However, all three specimens occur at the same locality, the last two are known to be distorted, so that there is a possibility of their belonging to the same species, at least in our present lack of knowledge of the changes in proportion taking place in the structure of the conch at different stages of growth.

Endoceras akpatokense new species.

Plate IV, Fig. 1, and Text-Figs. 1, 2.

(A 6845.)

The holotype is a fragment of a conch about 190 mm. long. It consists of the apical end of the conch, the overlying part of the siphuncle, and the median part of the ventral wall of the conch. Its ventral vertical outline is straight along its entire length. From this ventral outline the dorsal outline of the lower part of the preseptal cone diverges at an angle of about 30 degrees, this part of its dorsal outline being faintly concave, the dorsoventral diameter of the apical end enlarging here from 8 mm. to 23·5 mm. in a length of 24 mm. Above this point the curvature of the dorsal outline reverses to convex, the dorsoventral diameter being 27 mm. at a point 39 mm. above the base of the specimen. Here the basal margin of the first septal neck is exposed along the dorsal outline of the apical end. This septal neck is 8 mm. long and curves concavely inward for a depth of 2 mm., forming a short camera of shallow depth. The next septal annulation appears to be 12 or 13 mm. farther up dorsally, where the dorsoventral diameter of the siphuncle is 28·5 mm. The following septal annulations occur at intervals of 16, 19, 20, 19, and 19 mm., in ascending order. The dorsoventral diameter of the siphuncle decreases from 27·5 mm. at 75 mm. above the base of the specimen to 25 mm. at a point 45 mm. farther up, and to 23 mm. after an additional interval of 30 mm. At points 77·5, 93·0, and 102·0 mm. above the base of the specimen the siphuncle appears to be in contact with the median part of the ventral wall of the conch at the septal annulations, but is free from this wall at the broad intermediate grooves formed by the septal necks where they curve concavely inward along the mid-length of the camerae. However, farther up, the siphuncle becomes free even at the septal annulations, being 3 mm. distant from the ventral



Text-figs. 1–7.

wall of the conch at a point 165 mm. above the base of the specimen. All of the septal annulations slope downward in a dorsad direction, toward the interior of the conch, at an angle of 20 degrees with the horizontal. A vertical dorsoventral section through the mid-length of the specimen exposes the lower half of the spiess or spiculum. The tip of this spiculum is 65 mm. above the base of the specimen. At 40 mm. above this tip its dorsoventral diameter is about 10 mm., and between 50 and 60 mm. farther up the spiculum comes in contact with the inner walls of the siphuncle, the total length of the spiculum being almost 100 mm. The spiculum tapers evenly downward, but is slightly sinuous in direction along its lower half, its tip being central in location. At 90 and 110 mm. above the base of the specimen the septa rise at an angle of 30 degrees with the horizontal toward the interior of the conch on the dorsal side of the siphuncle. This suggests that the conch probably was not much larger than a little over twice the diameter of the siphuncle at the upper end of the specimen. The surface of the shell is crossed by faint and relatively distant transverse striae. Between 35 and 50 mm. above the base of the specimen four of these lines occur in a length of 10 mm. along the ventral outline. Between 65 and 80 mm. above its base these lines are between 3·5 and 4·5 mm. apart, sloping downward in a dorsal direction at an angle of 20 degrees with the horizontal.

Occurrence.—Akpatok Island, at an elevation of 650 feet.

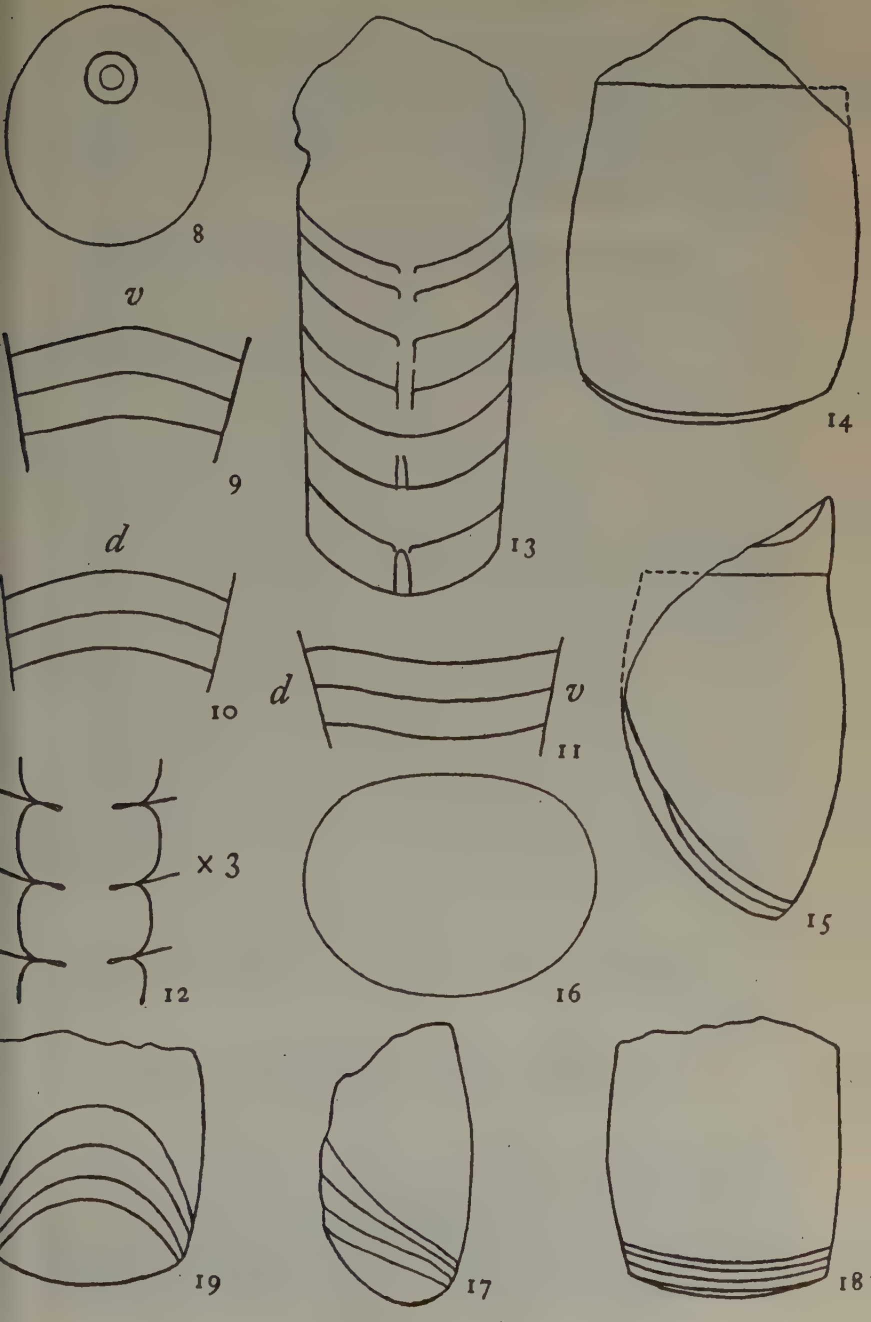
Remarks.—Compared with the type of *Endoceras coxi* the number of camerae in a length equal to the diameter of the siphuncle is about the same, but the relative distance of the siphuncle from the ventral wall of the conch appears to be less.

This specimen is of interest chiefly because it preserves the preseptal apical end. This apical end apparently varies considerably in different species of *Endoceras*. For instance, in *Endoceras faberi* Foerste (1929,[2] 302, pl. 63, fig. 2), from the upper part of the Richmond formation at Madison, Indiana, the initial end of the apical end is more nearly in line with the central axis of the conch, its ventral outline here being convex. Unfortunately, the structure of the genotype still is unknown.

Endoceras sp.

(A 6832.)

A fragment of a siphuncle is preserved for a length of 190 mm., is circular in cross-section, and enlarges in this length from 20·5 mm. at its base to 22·5 mm. at its top. At the top of the specimen there are four septal annulations in a length equal to the diameter of the siphuncle, indicating three camerae within this length. The diameter of the conch, unfortunately, is unknown. The septal annulations slope downward in a dorsad direction at an angle of 25 degrees with the horizontal. Ventrally these annulations are more flattened and



Text-figs. 8–19.

their median parts rise in the form of subangular crests, probably from contact with the ventral wall of the conch.

Occurrence.—Akpatok Island, at an elevation of 650 feet.

Remarks.—From the preceding specimen, which is from the same horizon, this specimen is distinguished readily by the greater number of camerae in contact with the siphuncle in a length equal to the diameter of this siphuncle.

Shamattawaceras cf. *ascoceroides* Foerste and Savage.

Plate IV, Figs. 4, 5; and Text-figs. 14–16.

(A 6841.)

Shamattawaceras ascoceroides Foerste, A. F., and Savage, T. E., 1927. Ordovician and Silurian Cephalopods of the Hudson Bay Area. *Denison Univ. Bull., Journ. Sci. Labs.*, xxii, 32, pl. 3, figs. 1 A, B, C.

Specimen consisting of a living chamber to which a trace of the ventral side of the uppermost camera still is attached. The ventral outline of this living chamber is 47·5 mm. long and has a radius of convex curvature of 60 mm. except at its top, where for a length of 8 or 9 mm. the curvature reverses to slightly concave. The lateral outlines have a convexity of about 70 mm., except at the top, where there is a slight tendency toward elongation into a neck. The lateral diameter of this living chamber enlarges from 39 mm. at its base to 44·5 mm. at mid-length and then contracts to 42 mm. at its top. The margin of the aperture appears to be directly transverse. The suture of the uppermost septum rises strongly toward the dorsal side of the conch, reaching a height of at least 30 mm. above its ventral margin. This suture curves downward laterally about 2 mm., the concavity of the septum reaching 5 mm., the latter facing diagonally downward in a dorsad direction. The ventral side of the uppermost camera is scarcely 1 millimetre in length. The specimen is a cast of the interior of the conch and its surface is smooth.

Occurrence.—Akpatok Island, at an elevation of 450 feet.

Remarks.—This specimen differs from the holotype of *Shamattawaceras ascoceroides* (Text-figs. 17–19) only in its size, the living chamber of this holotype having a length of only 37 mm. ventrally.

Orthoceras ungavaense new species.

Text-fig. 13.

Holotype: A 6842.

Conch about 58 mm. long, circular in cross-section, enlarging in diameter from 28 mm. at its base to 32 mm. at its top. The lower five camerae occupy a length of 40 mm., the following two camerae having lengths of 7 mm. and 3·5 mm. respectively. Immediately above this uppermost camera the exterior of the specimen has an indication of an additional camera only 1 mm. long, but of the latter there is no trace in the interior of the conch. The concavity of the septa equals 9 mm. The siphuncle is central in location. Its passage through the septum is about 2 mm. in diameter, enlarging to 2·25 mm. at mid-length of the camera. The septal neck is thickened and is about 0·75 mm. long, the connecting ring being much thinner. The specimen is a cast of the interior of the conch and its surface is smooth.

Occurrence.—Akpatok Island, at an altitude of 450 feet.

Remarks.—Compared with *Orthoceras clarksvillense* Foerste (1924, 220, pl. 42, figs. 1A, B), from the Waynesville member of the Richmond group at Clarksville, Ohio, the camerae are relatively shorter and the diameter of the siphuncle is smaller.

Spyroceras sp.

Text-fig. 5.

(A 6843.)

Conch 22 mm. long, 16 mm. in diameter, with six annulations in a length of 15 mm. Annulations rising 0·5 mm. above the intervening grooves, the latter of about the same width as the annulations. Cross-illumination reveals obscure traces of markings interpreted as indicating five vertical ribs in a width of 3 mm. and four transverse raised lines in a length of 2 mm., obscurely indicated beneath a covering of crystalline calcite.

Occurrence.—Akpatok Island, at an elevation of 200 feet.

Remarks.—In the relative number of annulations in a length equal to the diameter of the conch this specimen resembles *Spyroceras balteatum* (Billings) (Foerste in Twenhofel 1928, 274), from the English Head formation of the Richmond group on Anticosti. However, the annulations of the Anticosti species are narrower, the intervening grooves are flatter, and both the vertical and transverse striae are finer and more numerous.

Spyroceras cf. *aquilonare* (Troedsson).

(A 6835.)

Text-fig. 6.

Cf. *Dawsonoceras* (?) cf. *aquilonare* Troedsson, G. F., 1926. "On the Middle and Upper Ordovician faunas of Northern Greenland. 1, Cephalopods," *Med. om Grønland*, lxxi, Nr. 1, p. 36, pl. 10, figs. 4, 5, 6.

Conch 170 mm. long, irregularly curved owing to distortion after the death of the animal. Of this length 108 mm. is camerated, the overlying part, 62 mm. long, being regarded as belonging to the living chamber, of which the aperture is not preserved. The larger diameter increases from 31 mm. at the lower end of the specimen to 41 mm. at the base of the living chamber and then decreases to 39 mm. at the top of the latter. The number of annulations in a length equal to the larger diameter of the conch equals 4·3 at its lower end, 4·65 at the top of the phragmacone, and 4·5 at the top of the living chamber. The crests of these annulations rise fully 2 mm. above the intervening grooves and are only 2 mm. wide, being distinctly narrower than the latter. The sutures of all the septa are directly transverse and are located at the bottom of the transverse grooves. There are about 3·3 camerae in a length equal to the larger diameter of the conch. At a diameter of 38 mm. the concavity of the septa equals 6·5 mm., the siphuncle is central in location, and its passage through the septum is 2·7 mm. in diameter. There are obscure traces of vertical ribs, about four in a width of 10 or 11 mm. Finer lines are not preserved.

Occurrence.—Akpatok Island, found loose in the scree.

Remarks.—In the relative number, prominence, and angularity of the crests of its annulations this specimen resembles *Dawsonoceras aquilonare* Troedsson (1926), from the Cape Calhoun beds of north-western Greenland. In *Spyroceras microlineatum* Foerste (in Twenhofel, 1928, 274), from the Vauréal formation of the Richmond group on Anticosti, both the sutures and the crests of the annulations are distinctly sinuous.

Spyroceras sp.

Text-fig. 7.

(A 6830.)

Fragment of a conch 90 mm. long with a septum at its base, all apparently belonging to a living chamber at a gerontic stage of growth of the animal, judging from the conspicuous contraction of this chamber toward the aperture. At the annulation 10 mm. above the base of this chamber the larger diameter of this conch is 44 mm., contracting to 40 mm. at an annulation 48 mm. farther up, and to 39 mm. at the next following one, the next one in turn being either of the same diameter or slightly larger. The lower four annulations occur at intervals of 12 mm., the next at an interval of 14 mm., and the last at an interval of 10 mm. The intervening groove at the interval of 14 mm. is conspicuously deeper than the others, having a depth of nearly 3 mm., compared with 2 mm. for the underlying grooves. Compared with the grooves, the annulations are a little narrower, but they are not as angular as in the preceding specimen. The surface of the shell is marked by vertical ribs, about seven in in a width of 14 mm.; the finer markings are not preserved distinctly. The septum at the base of the specimen has a concavity of 8 mm., the siphuncle here is central in location, and its passage through the septum is 4·5 mm. in diameter.

Occurrence.—Akpatok Island, at an elevation of 300 feet.

Remarks.—This specimen differs from typical *Spyroceras aquilonare* (Troedsson) in the broader rounding of the crests of its annulations. The contraction of the living chamber toward its aperture is a feature noted in other specimens of *Spyroceras*.

Spyroceras wordiei new species.

Plate IV, Fig. 3.

Holotype: A 6829.

Specimen 42 mm. long. Its lower part, 25 mm. in length, consists of a part of the conch sectioned vertically through the siphuncle, and the upper part, 17 mm. in length, is a poor impression left in the matrix by the exterior of the shell. The diameter of the lower part enlarges from 7·3 mm. at its base to 9·8 mm. at a point 23 mm. farther up. The camerae are irregular in length. At a diameter of 8 mm. the camera is 1·5 mm. long, the following camerae in consecutive order having lengths of 1·75, 2·0, 2·1, 2·2, 2·6, 2·6, 2·0, and 2·0 mm., the diameter of the conch at the top of this series being almost 10 mm. The concavity of the uppermost septum equals 2·6 mm. The siphuncle is subcentral in location and its diameter enlarges from 1 mm. at its base to 1·25 mm. at its top. The number of annulations in a length of 10 mm. is almost constant, varying from 10·5 at the lower end of the specimen to 10 at the top of that part of the specimen showing its interior structure. The crests of the annulations are angular, rise one-fourth of a millimetre above the intervening grooves, and are distinctly narrower than the latter. The upper part of the specimen, preserving only an impression of the exterior of the shell within the matrix, indicates four annulations in a length of 5 mm. where the diameter of the conch is 12 mm., or about nine in a length of 12 mm. There are obscure traces of vertical ribs, too poor for actual counting.

Occurrence.—Akpatok Island, at an elevation of 650 feet.

Remarks.—This specimen resembles *Spyroceras chicottense* Foerste (in Twenhofel, 1928, 276), from the Chicotte formation of the Clinton group of Silurian strata on Anticosti Island, in the rate of enlargement of the conch and the relative number of its annulations, but its camerae are shorter and its siphuncle is smaller in diameter. It is given the name of Mr. J. M. Wordie, authority on Polar matters.

Spyroceras sp.

(A 6839.)

Conch 88 mm. long, very much flattened by pressure after the death of the animal, preserving well only the transverse annulations. Its maximum diameter in its present condition enlarges from 8 mm. at its base to 19 mm. at its top. The number of annulations in a length equal to the maximum diameter of the conch equals 8·5 at a diameter of 10 mm., and 6·5 annulations at 17 mm. The annulations are narrow, much narrower than the intervening grooves; they are abruptly elevated, but not to a great height, the intervening grooves tending to be relatively shallow. At a diameter of 10 mm. there are five vertical raised lines in a width of 2 mm.

Occurrence.—Akpatok Island, at an elevation of 800 feet.

Sedgwick Museum, cat. No. A 6839.

Remarks.—Compared with the preceding specimen the number of annulations in a length equal to the diameter of the conch appears to be smaller, and the grooves between the annulations are more shallow.

Huronia septata Parks.

Plate IV, Fig. 6.

(A 6831.)

Fragment of a siphuncle 150 mm. long, including nine segments. The length of these segments increases from 14 mm. at the first segment to 17·5 mm. at the seventh. The lateral diameter increases from 32 mm. at the first segment to 35·5 mm. at the seventh. The corresponding dorsoventral diameters are 31 mm. and 34 mm. The septal grooves at the base of these segments slope downward in a dorsad direction at an angle of 5 degrees with the horizontal. The lower part of each segment, where adnate to the upper surface of the underlying septa, presents slightly concave vertical outlines. Along this area of adnation the dorsoventral diameter of the seventh segment enlarges from 27 mm. at its base to 31 mm. at its top, the upper margin of this area rising from 7 mm. above its base dorsally to 10 mm. ventrally. The upper part of each segment is almost evenly convex, the line of maximum convexity rising from 11 mm. above the base of the segment dorsally to 12 mm. ventrally. A break across the siphuncle between its third and fourth segments reveals both radiating and concentric lines.

Occurrence.—Akpatok Island, at an elevation of 650 feet.

Westonoceras sp.

Plate IV, Fig. 2; Text-figs. 8–11.

(A 6834.)

Cyrtoceras manitobense Schuchert, 1900. "On the Lower Silurian (Trenton) fauna of Baffin Land," *Proc. U.S. Nat. Museum*, xxii, 170.

Westonoceras cf. *iowense* Foerste and Teichert, 1930. *Denison Univ. Bull., Journ. Sci. Labs.*, xxv, 283, pl. 55, figs. 3A, B, C.

Fragment of a conch 75 mm. long laterally, sufficiently depressed dorsoventrally along its upper half to make it impossible to determine its exact dimensions or cross section there. Only a part of the phragmacone is preserved. Of this, the dorsal outline is concave and the ventral outline convex, but the original rate of curvature has been changed by the distortion of the conch. At the base of the specimen, where there is no evidence of dorsoventral depression, the dorsoventral diameter is 27 mm. and the lateral one is 21·5 mm. At a point 50 mm. farther up, where the dorsoventral diameter at present is 43·5 mm., the lateral one is approximately 40 mm. The difference in these two ratios is due to the dorsoventral compression of the upper part of the specimen. Along the median part of the lateral sides the length of the camerae varies from 4·5 mm. at the lowest camera to 5 mm. at the fifth camera, and to 6·5 mm. at the ninth camera. The sutures of the septa curve only slightly downward laterally. The dorsal saddles are broadly and evenly rounded. The ventral ones tend to be slightly angular along their median parts, but much less than in other species of *Westonoceras* studied so far. At a dorsoventral diameter of 36 mm., the concavity of the septum is about 3·5 mm. Here the centre of the siphuncle is 10 mm. from the ventral wall of the conch, and its passage through the septum is 3·5 mm. in diameter. At a dorsoventral diameter of 28·5 mm., the segment of the siphuncle there exposed is 4·5 mm., long, 7·5 mm. in diameter at mid-length, 5·5 mm. in diameter at contact with the overlying septum, and its form is that of a very short barrel with moderately convex vertical outlines. The specimen is a cast of the interior of the conch, and its surface is marked with fifty vertical ribs, the latter being broad and low and separated by vertical grooves which are distinctly narrower. The ribs evidently correspond to vertical grooves on the interior of the shell.

Occurrence.—Akpatok Island, found loose in the scree.

Remarks.—Compared with the holotype of *Westonoceras iowense* Foerste and Teichert (1930, 281), from the Stewartville formation near Clermont, Iowa, the sutures of the septa of the specimen described here curve downward less conspicuously and the ventral saddles are less angular. However, in the specimen described immediately below the sutures of the septa curve downward more strongly and the ventral saddles were probably more angular, and yet, in other respects, these two specimens look much alike and lithologically could have come from the same layer. Judging from more recent experience, the more characteristic differences between species of *Westonoceras* are to be found in the upper halves of their conchs, rather than along their lower ends, so that it does not seem advisable to give a specific name to the fragments here in question.

From *Westonoceras ornatum* (Troedsson) (1926, 94), found in the Cape Calhoun formation in north-western Greenland, this specimen differs not only in the smaller downward curvature of the sutures of its septa but also in its distinctly longer camerae at the same stages of growth.

Westonoceras sp.

Text-fig. 12.

(A 6833.)

Part of a fragment of a phragmacone 105 mm. long. The dorsoventral diameter enlarges from 22 mm. at its base to 29 mm. in a length of 20 mm. In this interval the camerae increase in length from 3·5 mm. to 4 mm. The sutures of the septa here curve downward about 4 mm. laterally. The centre of the siphuncle is 10 mm. from the ventral wall of the conch. The diameter of the uppermost segment within this length of 20 mm. is 7·5 mm. at mid-length of the camera and narrows to 6·5 mm. at contact with the overlying septum. The septal necks are about one-eighth of a millimetre long and the brim curves abruptly outward and rises until its outer margin comes in contact with the overlying septum. At its passage through the septum this neck is 2·5 mm. in diameter. The general form of this segment is barrel-shaped, but very short. Farther up, between 44 and 55 mm. above the base of the specimen, two camerae occur in a length of 11 mm. Between 80 and 92 mm. above the base, two camerae occupy a length of 12 mm. The specimen is a cast of the interior of the conch and it is ribbed vertically as in the preceding specimen.

Occurrence.—Akpatok Island, at an elevation of 270 feet.

Remarks.—This specimen has precisely the same tint of reddish brown as the preceding one, and both probably came from the same layer and belong to the same species, notwithstanding the differences here noted.

STROMATOPOROID.

Beatricea undulata Billings.

(A 6838.)

Beatricea undulata Billings, 1857. *Geol. Surv. Canada, Rept. of Progress for* 1853–6, 344.

Beatricea undulata Foerste, 1909. *Denison Univ. Bulletin, Journ. Sci. Labs.*, xiv, 298, pl. 8, fig. 3.

A transverse fragment, 30 to 40 mm. long, its diameters varying from 65 to 80 mm. in different directions. With eight prominent vertical ridges and some intermediate smaller ones irregularly arranged.

Occurrence.—Akpatok Island, at an elevation of 650 feet.

III. SUMMARY.

The cephalopods and stromatoporoid collected from Akpatok Island, Ungava Bay, N.W.T., in 1931, by Cox, are described by Foerste in this communication as follows :—

Endoceras coxi sp. nov., *Endoceras* sp. (resembling *E. coxi*), *Endoceras akpatokense* Foerste, *Endoceras* two spp., *Shamattawaceras* cf. *ascoceroides* Foerste and Savage, *Orthoceras ungavense* Foerste, *Spyroceras* sp. (resembling *S. balteatum* (Bill.) in some respects), *Spyroceras* cf. *aquilonare* Troedsson), *Spyroceras wordiei* Foerste, *Spyroceras* two spp., *Huronia septata* Parks, *Westonoceras* sp., and *Beatricea undulata* Billings.

Tentative correlations of the Akpatok limestones with other areas are drawn from this material. The greater part of the limestones appear to correlate with the Red River formation of Manitoba. The lowest horizons, containing *Westonoceras*, apparently correspond to part of the Nelson River formation of the Hudson Bay region; the intermediate horizon, with *Shamattawaceras* and *Huronia*, apparently to the Shamattawa formation of the same locality; while the horizon with *Beatricea* (650 feet above sea-level) is of Richmond age. The extent to which the remainder of the fauna, as yet identified, agrees with this is reviewed.

IV. LITERATURE.

Bell, R., 1899. Report A, *Ann. Rept. Geol. Surv. Canada for* 1897. New Series, x.

Cox, Ian, 1933 [1]. "On Climacograptus inuiti sp. nov. and its development," Geol. Mag., LXX, 1–19.

—— 1933 [2]. "Rejuvenation on Akpatok Island; a topographical unconformity in North-Eastern Canada," Geol. Mag., LXX, 67–83.

—— 1933 [3]. "Richmondian Trilobites from Akpatok Island," Geol. Mag., LXX, 359–373.

—— 1936. Revision of the genus *Calapoecia, Nat. Mus. Canada, Bull.* 80, Geol. Ser. 53.

Dowling, D. B., 1900. "Rept. on the Geology of the West Shore and Islands of Lake Winnipeg. Ann. Rept. for 1898," *Geol. Surv. Canada*, new series, xi.

Foerste, Aug. F., 1924 [1]. "Silurian Cephalopods of Northern Michigan," *Contrib. Mus. Geol. Univ. Michigan*, ii, 19–120.

—— 1924 [2]. "Notes on American Paleozoic Cephalopods," *Denison Univ. Bull.*, xx, 193–267.

—— and Savage, T. E., 1927. "Ordovician and Silurian Cephalopods from the Hudson Bay area," *Denison Univ. Bull.*, xxii, 1–107.

—— 1928 [1]. "American Arctic and Related Cephalopods," *Denison Univ. Bull.*, xxiii, 1–110.

—— 1928 [2]. "The Cephalopods of Putnam Highland," in Contributions to the Geology of Foxe Land, Baffinland, *Cont. Mus. Pal. Univ. Michigan*, iii, 25–69.

—— 1929 [1]. "The Cephalopods of the Red River Formation of Southern Manitoba," *Denison Univ. Bull.*, xxiv, 129–235.

—— 1929 [2]. "Three Studies of Cephalopods," *Denison Univ. Bull.*, xxiv, 265–381.

—— and Teichert, Curt, 1930. "The Actinoceroids of East-Central North America," *Denison Univ. Bull.*, xxv, 201–296.

Miller, A. K., 1932. "The Cephalopods of the Big Horn formation of the Wind River Mountains of Wyoming," *Connecticut Acad. Arts and Sci.*, xxxi, 193–297.

Parks, W. A., 1910. "Ordovician Stromatoporoids," *Univ. Toronto Studies, Geol. Series*, No. 7, 1–52.

Savage, T. E., and van Tuyl, F. M., 1919. "Geology and Stratigraphy of the area of Paleozoic rocks in the vicinity of Hudson and James Bays," *Bull. Geol. Soc. Amer.*, xxx, 339–378.

Slocom, A. W., 1914. "Trilobites from the Maquoketa beds of Fayette county, Iowa," *Iowa Geol. Surv., xxvth Ann. Rept.*

Schuchert, Charles, 1900. "On the Lower Silurian (Trenton) Fauna of Baffinland," *U.S. Nat. Museum Proc.*, xxii, 143–177.

Troedsson, G. T., 1926. "On the Middle and Upper Ordovician Faunas of Northern Greenland," *Medd. om Grønland*, lxxi.

—— 1928. "On the Middle and Upper Ordovician Faunas of Northern Greenland," *Medd. om Grønland*, lxxii.

TWENHOFEL, W. H., 1928. " Geology of Anticosti Island," *Geol. Surv. Canada Memoir*, 154, 1–350.

WHITEAVES, J. F., 1899. " Recent discovery of rocks of the age of the Trenton Formation at Akpatok Island, Ungava Bay, Ungava," *Amer. Journ. Sci.*, ser. 4, vii, 433–4.

TEXT-FIGS. 1–7.—CEPHALOPODS FROM AKPATOK ISLAND.

TEXT-FIGS. 1, 2.—*Endoceras akpatokense* Foerste. 1, Diagrammatic lateral view, with ventral outline on left, showing preseptal cone, gradual separation of siphuncle from ventral wall of conch, the spiculum occupying the cavity left at the top of the calcareous deposits filling the lower part of the siphuncle, and the course of the septal annulations crossing the siphuncle diagonally. 2, Cross-section at top of preseptal cone, oriented as in Text-fig. 1. Sedgwick Museum, A 6845. See also Pl. 1, Fig. 1. Reduced to nine-tenths of natural size.

TEXT-FIGS. 3, 4.—*Endoceras coxi* Foerste. 3, Cross-section of conch showing relative size and location of siphuncle. 4, Vertical section of same, in direction indicated by preceding figure. Sedgwick Museum, A 6835. Reduced to nine-tenths of natural size.

TEXT-FIG. 5.—*Spyroceras* sp. Lateral view showing annulations. Sedgwick Museum, A 6843. Reduced to nine-tenths of natural size.

TEXT-FIG. 6.—*Spyroceras* cf. *aquilonare* (Troedsson). Lower part of specimen 170 mm. long, showing form of annulations, also septum at its base and sutures in the grooves between the annulations. Sedgwick Museum, A 6835. Reduced to nine-tenths of natural size.

TEXT-FIG. 7.—*Spyroceras* sp. Living chamber, showing form of annulations, also the septum at its base. Sedgwick Museum, A 6830. Reduced to nine-tenths of natural size.

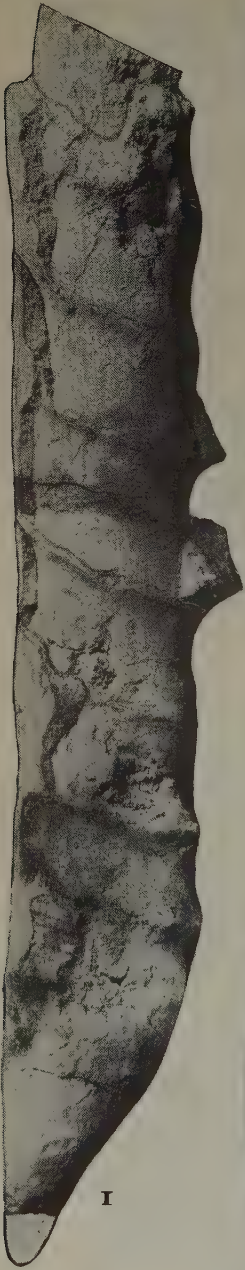
TEXT-FIGS. 8–19.—CEPHALOPODS FROM AKPATOK ISLAND.

TEXT-FIGS. 8–12.—*Westonoceras* sp. 8, Cross-section of conch showing location of siphuncle, with ventral outline at top. 9, Ventral side of conch, showing slightly angulate saddles of sutures of septa. 10, Dorsal side, with more evenly rounded saddles. 11, Lateral view, showing course of sutures of septa; d, dorsal side; v, ventral side. 12, Lateral section through siphuncle, magnified 3 diameters. Sedgwick Museum, A 6834 for Text-figs. 8–11, A 6833 for Text-fig. 12. See also Plate IV, fig. 2. Reduced to nine-tenths of natural size.

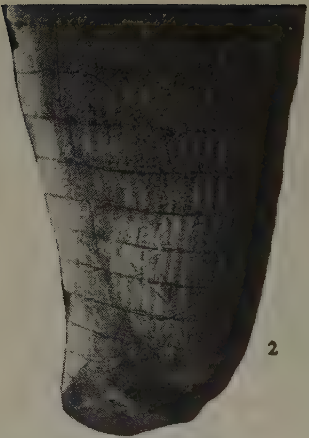
TEXT-FIG. 13.—*Orthoceras ungavaense* Foerste. Vertical section through siphuncle, showing length of septal necks and cylindrical form of connecting rings, the latter being poorly preserved. Sedgwick Museum, A 6842. Reduced to nine-tenths of natural size.

TEXT-FIGS. 14, 15, 16.—*Shamattawaceras* cf. *ascoceroides* Foerste and Savage. 14, Ventral view of living chamber, showing trace of uppermost camera. 15, Lateral view with ventral outline on right, part of uppermost camera retained at base, upper part of dorsal outline restored. 16, Cross-section with flattened ventral side at top. Sedgwick Museum, A 6841. Compare with Text-figs. 17–19. See also Plate IV, figs. 4, 5. Reduced to nine-tenths of natural size.

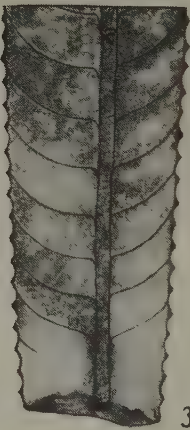
TEXT-FIGS. 17, 18, 19.—*Shamattawaceras ascoceroides* Foerste. Holotype. 17, Dorsal view, showing dorsal saddles increasing in elevation. 18, Lateral view, with ventral outline on right. 19, Ventral view of living chamber with three camerae at its base. Shamattawa River, south-west of Hudson Bay; in horizon 1 of Shamattawa limestone. Collection of Professor T. E. Savage. Reduced to nine-tenths of natural size.



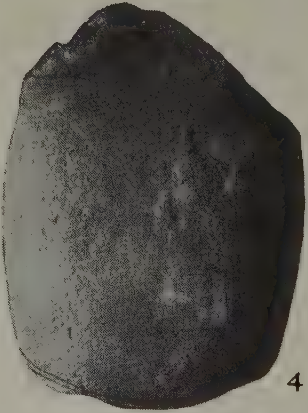
1



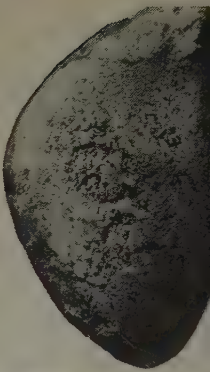
2

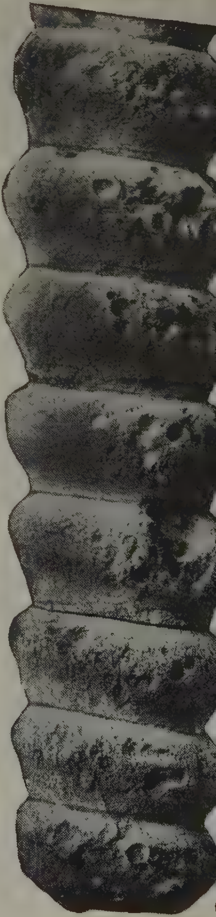


3



4





Cephalopods from Akpatok Island.

PLATE IV.

Cephalopods from Akpatok Island.

Fig.

1.—*Endoceras akpatokense* Foerste. Lateral view, with ventral outline of conch on left, showing preseptal cone and siphuncle with septal annulations. Sedgwick Museum, A 6845. See also Text-figs. 1, 2. Reduced to nine-tenths of natural size.

2.—*Westonoceras* sp. Lateral view with ventral outline on right, showing vertical ribs on cast of interior of phragmacone. Sedgwick Museum, A 6834. See also Text-figs. 8–12. Reduced to nine-tenths of natural size.

3.—*Spyroceras wordiei* Foerste. Dorsoventral section through siphuncle of lower half of a specimen 42 mm. long, showing relatively acute annulations. Magnified 3 diameters. Sedgwick Museum, A 6829. Reduced to nine-tenths of natural size.

4, 5.—*Shamattawaceras* cf. *ascoceroides* Foerste and Savage. 4, Ventral view of living chamber, with trace of uppermost camera at its base. 5, Lateral view with ventral outline on right; also with trace of uppermost camera at its base. Sedgwick Museum, A 6841. See also Text-figs. 14–16, and compare with Text-figs. 17–19. Reduced to nine-tenths of natural size.

6.—*Huronia septata* Parks. Lateral view of siphuncle with ventral outline on left. Sedgwick Museum, A 6831. Reduced to nine-tenths of natural size.

Rift Valley Impressions.

By Professor S. J. Shand.

"GEOLOGISTS should think to scale"; so Professor Daly has urged in one of his illuminating writings. Returning from a visit to the Rift Valley country, I realize that in the past I have failed to picture these remarkable valleys to scale. Perhaps I received a wrong impression in the beginning from the rather extravagant language used by some of the earlier writers: "a yawning abyss," says one; "walls as steep and abrupt as those of a grave," says another; "in many parts the walls are so precipitous that not even the most expert of cragsmen could scale them," says a third. Then the well-known drawings of the arch and the sunken keystone, and the rival diagram of the great ramps with a depressed block between them—although I knew that these were only diagrams, not scale drawings, I fear they played their part in perpetuating the early, extravagant impression. So it came to pass that when I stood at last between the walls of the great depression, the glow of satisfaction brought on by the realization of a long-cherished wish was chilled by a rather childish disappointment. Mine was not the case of the man who was shown a giraffe and said "I don't believe it!"; I believed in the giraffe, but it didn't come up to expectation!

I had read in Professor Gregory's book that as late as 1919, there was no road for wheeled traffic between Nairobi and the floor of the Rift Valley, and that the trains on the Uganda Railway were formerly run up and down the escarpment by cable. I imagined that the escarpment presented almost insuperable difficulties; but in place of terrifying crags I found well grassed and wooded slopes which rarely even approach the vertical. In reality the Kikuyu escarpment presents no difficulties that can compare with those that faced the road- and railway-engineers of South Africa in making the ascent from the coastal plain to the Karroo.

Upon another occasion I rolled by car over some well-rounded hills (the Mau escarpment!) on the road to Uganda, and came some days later to Lake Albert, the "yawning abyss" of Sir H. M. Stanley. The road book said "road very dangerous—800 foot drop". Here, I thought, I shall be thrilled at last. But I found that the great drop is spread over a distance of four miles, only the last third being at all steep; and again I felt the chill of disappointment. Was this grassy bank the great ramp of the pictures? They tell me the Albert escarpment is much steeper on the Belgian side than where I saw it, above Butiaba; but my faith in the great ramps had received a stunning blow. Is it really necessary, I wondered, to throw the whole continent of Africa into tectonic convulsions in order to explain this not very impressive declivity?

I realize that the intensity of a geotectonic process is not to be judged by physiographic evidence alone. On the other hand, both the rift theory and the ramp theory are nothing more than alternative attempts to explain physiographic features. Thus my disappointment was not just that of a tourist who finds the view less wonderful than he expected, for I had the feeling that the foundations of two widely-accepted theories had slidden away beneath my feet.

I realized at last that the depth of the African rifts, although impressive when stated in feet, is quite insignificant in relation to their width. The extreme difference of level in the eastern rift-valley, measured across its length, approaches 7,000 feet. This difference is found between Lake Elmenteita and the highest peak of the Aberdare Range; but these places are nearly 30 miles apart. Along the same line the floor of the rift-valley is 30 miles wide, so the proportion between minimum width and maximum depth is 22½ : 1. But the mean ratio of width to depth in the central segment of the eastern rift is much greater than this; it is probably not less than 75 : 1 for the whole region between Lake Baringo and Lake Magadi.

It is most instructive to plot a section, on true scale, from the Indian Ocean to Lake Victoria, crossing the deepest part of the Kenya rift-valley. The distance is some six hundred miles. On such a section the rift-valley is all but invisible. Stranger still, Professor Gregory's great arch, of which the rift-valley is but the sunken keystone, is all but invisible. It is necessary to remember that the highest parts of the section are built of lava and tuff, the thickness of which must be deducted from the observed height of the section, since they represent matter superimposed upon the

Gregorian arch. The full thickness of the volcanic series is not known; but at Ulu, where the series begins, and again at Fort Ternan where it ends, the altitude of the underlying gneiss is just over 5,000 feet. If a line is drawn on the section, from Lake Victoria (3,700 feet) to sea-level in the Indian Ocean, it appears that the arch rises some 2,500 feet above this line. A rise of only ½ mile in a span of 600 miles hardly deserves to be called an arch at all. Of course, it may have been higher before the keystone fell in, but if the arch was able to sink as a whole, why should the keystone fall in? And having begun to fall in—a great block 300 miles long and 40 miles wide—why did it sink only a few thousand feet? Of course, such questions are unanswerable, but they arise unavoidably whenever one tries to form a picture, to scale, of the growth and collapse of the Gregorian arch. In short, is it necessary for the whole continent of Africa to be heaved up and down in order to explain a relatively insignificant furrow across its face?

The process of disillusionment was not confined to the height of the escarpments; their structure too revealed surprising departures from the familiar picture. In planning my East African tour, I formed the idea of exploring at least one small section of one of the great escarpments from top to bottom. I had no notion of making new discoveries, but I wished to see for myself the effects of the great boundary faults of the rift-valley, to study step-faulting, and to collect specimens of the lavas that build the escarpment. For this purpose no section seemed so suitable as the Kedong scarp, where the railway-line makes the slopes accessible and affords many cuttings through solid rock. Professor Gregory said of this scarp that "the Kijabe buttress seems to have buried the southern continuation of the Settima fault"; and in his text-figures 33 and 34 he drew a strong fault along the face of the Kedong scarp, between Kijabe hill and the crest of the escarpment. Mr. Murray-Hughes follows Professor Gregory in this matter, for in the map that accompanies his recent bulletin[1] he traces the main boundary fault of the rift-valley right along the Kedong scarp, crossing the railway-line between Kijabe and Escarpment stations.

The Kedong scarp is steep, but it carries a number of large and small terraces arranged *en échelon* along its front. The Kijabe terrace, near the base of the scarp, is particularly well developed and has a width of about half a mile. The higher terraces are narrower, though well defined; the highest of all, at Escarpment station, is again a broad one. Accepting the view that the Kedong scarp is a fault-scarp, it was natural to picture these terraces as fault-steps. The broad Kijabe step, with its steep rocky front, fitted particularly well into such a picture.

I ranged up and down the Kedong scarp for five days, and at the end of that period I had failed to find any indication of the presence of a longitudinal fault in the escarpment. From Uplands (7,689 feet) down to Kijabe (6,787 feet) the scarp is formed of a succession of thick trachyte flows with tuff beds between them. The trachytes are all alike, having insets of sodic orthoclase in a light grey groundmass composed of felspar laths, aggregates of a dark brown amphibole (which resembles barkevikite, though its optical properties are hard to determine precisely), some aegerine grains, and abundant interstitial quartz. The same rock continues to form the scarp at least as far south as Limuru. But the base of the Kedong scarp is formed of a totally different rock, a strongly porphyritic olivine-basalt of striking and distinctive appearance, which outcrops all round the base of Kijabe hill and continues southwards beneath the tuff of the Kijabe terrace.

---

[1] *Geol. Survey of Kenya*, Report No. 3, 1933.

The structure of the Kijabe terrace is interesting. The olivine-basalt which forms its base is covered by at least a hundred feet of soft pisolitic tuff which can be followed, by way of a deep gorge, far back into the escarpment. The nearly level surface of the terrace is cut in tuff, not in basalt. The preservation of the tuff in this exposed position is due to the protection afforded it by a ridge of igneous rock which forms the western margin of the terrace, standing up above it like the rim of a tray and preventing the tuff from washing away. The ridge is formed neither of trachyte nor of basalt, but of a coarse-grained syenite-porphyry. The boundary between this porphyry and the tuff (and underlying basalt) is either an intrusive contact or a fault. If the latter, then it is a fault with downthrow *towards* the escarpment instead of away from it. Another fault separates the Kijabe terrace from Kijabe hill on the north, for the top of the olivine-basalt flow lies some two hundred feet higher in the hill than in the terrace; but this fault is transverse to the escarpment.

It follows from these observations that the Kijabe terrace is not a fault-step but an erosion feature. The higher terraces on the escarpment also appear to be ordinary erosion terraces, due to the alternation of harder trachyte flows with soft tuffs. The boundary fault of the rift-valley does not lie in the Kedong scarp.

I realize now that I ought not to have expected to find the boundary fault in this position. Gregory says the Kedong and Kikuyu scarps are at least pre-Pliocene in age; that is, at least some millions of years old; so it is in the highest degree improbable that the present escarpment should lie along the actual line of fault. The trachytes and tuffs of which the Kedong scarp is mainly composed yield readily to weathering and erosion, and the scarp must have receded far from the position of the fault that gave birth to it. This fault must lie west of Kijabe hill, possibly near Longonot station, where an earthquake focus has been reported. As I see it, both the present position and the great height of the Kedong scarp are due to the cutting back of the scarp into the Kikuyu highland. Erosion, then, has played a bigger part than is generally conceded in forming the present topography of the rift-valley.

Now that I have seen the Great Rift Valley with my own eyes, the keystone hypothesis seems just as unsatisfactory as the ramp hypothesis. It seems to me that every feature of the eastern rift might be explained adequately and satisfactorily without moving the rest of Africa either up, down, or sideways. It is only necessary to remember that the rift-valley region of Kenya is a site of very ancient and extensive volcanism, and that extensive volcanic action is nearly always followed by subsidence. Professor Gregory thought that subsidence was the cause of the superficial volcanism; he says explicitly that "the subsidence of the keystone of the East African arch forced the plastic rock material below up the adjacent cracks, and it was discharged in volcanic eruptions". To me it seems very much more probable that volcanism was the cause of the subsidence than subsidence the cause of the volcanism. Whatever may have happened in the beginning, it is at least certain that the later movements, to which the existence and form of the rift-valley are due, *followed* the main volcanic period. Now a central volcano gives rise to a circular caldera or "cauldron subsidence", as one sees at Menengai and Ngoro-Ngoro; is there any reason why a fissure-volcano should not give rise to a trench-like subsidence, the linear homologue of a caldera ?

It is very significant that the rift-valley is deepest, and yet its floor stands highest, just where the volcanic series is thickest; and that as the volcanic beds thin out north and south, the floor of the trough sinks too, and eventually the valley flattens out and loses its continuity beyond the borders of the lava-field. Thus the existence of the rift-valley is linked with the existence of the volcanic series and the amount of downthrow is linked with the thickness of the volcanic beds.

As I see it, the rift-valley of Kenya is a volcanic phenomenon and neither regional compression nor regional tension was a necessary condition of its formation, although its geographical position and its orientation were predetermined by an ancient system of fissures. The volcanic foci of East Africa have a meridional arrangement for reasons which take us far further back than the birth of the rift-valleys. A fissure once formed tends to be prolonged and perpetuated, hence the subsidence which followed the great volcanic epoch in East Africa took place along the direction of the same fissures up which the lava had risen, forming a series of intersecting trenches which, modified to some extent by subsequent erosion, constitute the present rift-valley of Kenya.

The gravest objection to this view is that it seems to dissociate the rift-valley of Kenya from the other rift-valleys of Africa, although they clearly belong to a single system. But if we admit that the fundamental condition for the genesis of all the rifts was the presence of an ancient system of fissures, does it follow that the cause of the movements that took place along these fissures in the Tertiary period must have been the same everywhere ? I think not.

In concluding this tale of disillusionment, I wish to say that nothing I have written is to be taken as reflecting on the work of the gallant band of pioneers to whom all our knowledge of the African rift-valleys is due. It is a reflection on myself for not having thought to scale, and for taking the hyperbolic language of the early travellers too literally. But it is no less a reflection on the government of Kenya for having failed in its duty to explore and make known the geological structure of the wonderful land that has been committed to its care. The problem is too big a one to be left to private enterprise. The discovery of gold in Kenya has at last compelled the government to establish a geological service. Is it too much to hope that pure science may be allowed to benefit as well as applied, and that we may soon have a detailed geological map of at least the central section of the Kenya Rift Valley ?

Enderbite, A New Member of the Charnockite Series.

By Professor C. E. Tilley.

THE term "charnockite series" is now commonly in use for a group of genetically related rocks ranging from ultrabasic to acid members having the chemical and mineralogical features of the rock suite of the type area of Madras (Holland, 1893, 1900). The acid member "charnockite" is defined by Holland (1926) as "essentially a hypersthene granite . . . composed of hypersthene, microcline, quartz, and iron ores . . .".

Washington (1916) published a mode of the type material analysed from St. Thomas's Mt., Madras, in which the quartz and felspars are given as quartz 40 per cent, microcline 48 per cent, oligoclase 6 per cent. Examples of the type rock show that although the amounts of microcline (which is a microperthite) and oligoclase show some variation, the microperthite is always dominant, and this feature is to be regarded as an essential part of the definition of charnockite.

In an examination of a group of rocks collected from Enderby Land, Antarctica, by the B.A.N.Z. Antarctic Research Expedition (1929–1931) under the leadership of Sir Douglas Mawson, a study has been made of a suite which includes ultrabasic, basic, and acid members of the charnockite series. A detailed description of these rocks is reserved for a special Expedition Report, but it is the object of this note to draw attention to an unusual member of the series.

Among the acid members occur typical charnockites conforming to the definition of Holland, but there are others which cannot be classed under this term.

The type example is a medium-grained grey plutonic rock in which blue quartz is conspicuous. On weathered surfaces the rock shows a faint foliation given by the linear disposition of hypersthene and by discontinuous bands of quartz. The constituents are quartz, plagioclase (antiperthite), hypersthene, and as accessory constituents, magnetite and zircon. Quartz is abundant in allotriomorphic grains and has a faint brown turbidity due to the presence of very fine inclusions, the scattered reflexion from which gives rise to the blue colour of the quartz seen in the hand specimens. The felspar forms plates of 1 mm. average grain size and multiple albite and pericline twinning is common.

In sections perpendicular to (001) (010) the extinction is $X^1 \wedge 010 = 19°$. Such sections are approximately perpendicular to the negative acute bisectrix. The composition is thus $Ab_{64}An_{36}$. In these plates of andesine occur rods of orthoclase (antiperthite). The great majority are orientated parallel to the "*c*" axis. In sections cut perpendicular to "*c*" these appear in cross section as dots along the (010) twin lines, but there are other spindles less commonly represented which appear in these sections approximately symmetrical to the twin lines and arranged at angles of 25°–30° to this direction. They correspond to an orientation parallel to the edges (110), (001).

Hypersthene is in subidiomorphic grains ½ mm. or less in diameter, noticeably pleochroic in pink to green tints. This pyroxene is free from alteration and the rock is remarkably free from secondary changes. The texture of the whole rock is typically granitic.

A specimen of this rock analysed gave the results indicated in Table I (1), and is there compared with the type charnockite (2). The distinctive features of this analysis are the low K_2O and high CaO combined with a high percentage of SiO_2. Owing to its simple mineralogy the mode of this rock is practically identical with the norm, and can be expressed as :—

Quartz	42·5
Antiperthite	48·5 ($Ab_{64}An_{36}$) 4·5 (orthoclase)
Hypersthene	3·0
Magnetite	1·0

It is clear from the analysis and the modal composition that it would be misleading to refer to this rock under the name charnockite, though it is associated with typical charnockites. Among rocks of similar acidity comparable analyses occur among rocks carrying hornblende or biotite and which are not members of the charnockite series. Mention might be made, e.g., of a "monzonite" from Shasta Co., California (Washington's Tables, 1917, p. 105), a granodiorite from Utsire Island, Norway (W.T., p. 105), and a trondhjemite from Mosterö, Norway (Johannsen, *Petrography*, vol. ii, p. 385). To refer to the Enderby Land rock as a granodiorite or trondhjemite would, however, obscure its very clear relations as a member of the charnockite series.

Examination of a group of rocks of the charnockite series from Southern India has revealed that a type similar to this Enderby Land rock is there represented. Examples which have been sliced at Cambridge come from Pallavaram (Madras area) and Ootacamund (Nilgiri Hills), and there are doubtless others.

TABLE I.

	(1)	(2)	Norm of (1)	
SiO_2	75·50	77·47		
Al_2O_3	13·92	11·00		
Fe_2O_3	0·48	1·04		
FeO	1·17	2·02		
MgO	0·52	0·43		
CaO	3·54	1·02	Quartz	42·3
Na_2O	3·64	2·86	Orthoclase	4·5
K_2O	0·74	4·14	Albite	30·9
P_2O_5	nil	nil	Anorthite	17·5
TiO_2	0·08	0·26	Corundum	0·6
MnO	nil	nil	Hypersthene	2·9
$H_2O -$	0·30	0·05	Magnetite	0·7
$H_2O +$	0·15	0·20	Ilmenite	0·2
			Symbol I.3.3. 4(5)	
	100·04	100·49		
Sp. Gr.	2·67	2·67		

(1) Enderbite, Proclamation Island, Enderby Land, Antarctica.
(2) Charnockite, St. Thomas's Mt., Madras, India.

F. D. Adams (1929), in his report on the geology of Ceylon, in describing rocks of the charnockite series refers to two rocks under the name "charnockite" and "rock intermediate between charnockite and quartz norite" of which analyses are published. These two rocks carry 1·33 per cent and 0·81 per cent of K_2O respectively, and though somewhat less acidic than the Enderby Land example they clearly belong to the same type.

It is evident, therefore, that the plagioclase-rich type of hypersthene granite (Enderby Land type) occurs in other charnockite areas. As the Enderby Land rock is not an isolated occurrence, and as the type may well be widespread, I venture to suggest the name *Enderbite* for an acid member of the charnockite series characterized by rhombic pyroxene in which plagioclase (oligoclase or andesine) is the essential felspar, as distinct from charnockite in which the essential felspar is a microperthite (Holland, 1900). In rocks containing both felspars the preponderating modal felspar could define the name. The special recognition of such a plagioclase-rich acid member will furthermore direct attention to the differentiation problems still awaiting solution among the acid derivatives of the charnockite series.

The strong development of antiperthitic texture in Enderbite, as with the perthitic textures in the rocks of the charnockite series, is doubtless symptomatic of a high temperature of consolidation of magmas of this series connected with their low water content. Crystallization is thus arrested at higher temperatures than in the case of other rock series.

It is significant in this connection that von Engelhardt (1936) finds that the microperthite-bearing members of the charnockite series contain unusually high mean percentages of BaO (charnockites 0·2 per cent, normal granites 0·05 per cent), a feature which he correlates with the observed preferential enrichment in barium of potash felspars of higher temperature consolidation.

BIRKREMITE.

This rock name was introduced by Kolderup (1903) for a rock already described in 1896. " The birkremites contain microperthite, quartz, and orthorhombic pyroxene as essential minerals. Acidic plagioclase may occur in varying amounts with the microperthite." (Kolderup, 1933.) A rock of this composition would, however, outside Norway be described as a charnockite.

Goldschmidt (1916) refers to the birkremites of Jotunheimen as containing a characteristic finely lamellated microperthite with spindles of oligoclase-albite. In many of the rocks such a microperthite forms the only felspar, in others it is accompanied by independent grains of oligoclase-albite with antiperthitic drops of potash felspar. These rocks appear to deserve no further distinction from the type defined by Holland in 1893, than to be described as charnockites (Birkrem type).

Tröger (1935) places birkremite and charnockite under his family of aplite granites and describes birkremite as a quartz-poor hypersthene alaskite. He distinguishes charnockite from it only by the presence of a genuine granulitic texture (" wie Birkremit, Granulitstruktur "). Such a textural criterion will not, however, bear examination. The type rock of St. Thomas's Mt. has a characteristic granitic texture which is shared also by other charnockites.

The Ekersund birkremites were first recorded by Vogt (1891, 1893) as bronzite granites. It is in reference to Vogt's description of these that Holland (1900, p. 135) has remarked " such a description applies exactly to the rock which is known to us in South India as charnockite ".

REFERENCES.

ADAMS, F. D. 1929. *Canadian Journal of Research*, i, 470, 474.
ENGELHARDT, W. VON. 1936. *Chemie der Erde*, x, 187.
GOLDSCHMIDT, V. M. 1916. *Vid Selsk. Skrifter, M.N.Kl.*, No. 2, 47.

Holland, T. H. 1893. *Journ. As. Soc. Bengal*, lxii, 162.
—— 1900. *Mem. Geol. Surv. India*, xxviii, 134.
—— 1926. Ibid., li, Pt. 1, 55.
Kolderup, C. F. 1896. *Bergens Mus. Aarbok*, No. 5, 16, 18.
—— 1903. Ibid., No. 12, 117.
—— 1933. "The Anorthosites of Western Norway," *Report of XVI Internat. Geol. Congress* (*Washington*), Preprint, p. 2.
Tröger, W. E. 1935. *Spezielle Petrographie der Eruptivgesteine*, 19–21.
Vogt, J. H. L. 1891. *Geol. För. Förh., Stockh.*, xiii, 492.
—— 1893. *Zeitschr. für prakt. Geol.*, 4.
Washington, H. S. 1916. *Amer. J. Sci.*, xli, 324.

Some Vertebrate Fossils from Ceylon.

By P. E. P. Deraniyagala.

Although fossil plants of Jurassic age are known from an area of about a square mile at Tabbova and Miocene marine invertebrates have been recorded from several coastal localities, there is no authentic record of vertebrate fossils from Ceylon. It had hitherto been suspected that local conditions were not conducive to the preservation of bones, but it now transpires that there are such fossils which are as interesting as those of India or Burma.

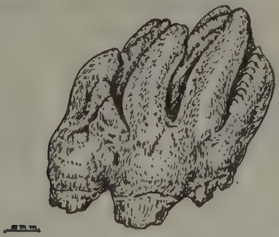
A collection of vertebrate fossils obtained by the writer from one coastal and several inland localities was thought to belong to the late Pliocene or early Pleistocene and was submitted to Dr. A. Tindell Hopwood of the British Museum for his opinion. He concurred with this estimate of their age as follows: "I do not know whether fossil mammals of Upper Siwalik age have been found in Ceylon before, but some of yours certainly are of that age."

This collection comprised the mineralized base of an antler of a small deer and a tooth, both obtained at a depth of 8 feet while boring for an artesian well at Ambalama, a coastal village in the Southern Province, where the Miocene deposits had been pronounced unfossiliferous; several broken elephant molars, the lower molar of a species of hippopotamus, and a bovine cannon bone; all from the Ratnapura District, at about 66 feet above sea-level and at a distance of about 32 miles from the sea. With the exception of the cannon bone, which was more superficial, the others were discovered at depths of 30 to 36 feet below the surface.

The strata of the Ratnapura system, which evidently correspond to the Upper Siwalik system of India, are best developed in the series of strike valleys and extend to the coast in some places. The sequence of the local beds is as follows: The uppermost, which usually lies at about 6 to 12 feet below the surface earth is an irregularly disposed stratum of pink, yellow, or grey loess, known in Sinhalese as "Samara"; beneath it is a bluish grey clay, often mixed with sand. This is probably preglacial, and is known as "Valan mätté" (pot clay). Farther down is the

" Illama ", a stratum of quartz pebbles which vary in colour and range in size from that of " small shot to a football ". In some places this Illama is found at a considerable depth, and Coomaraswamy (1904) records 120 feet at Botiyatenna, near Rakvana. Deeper down is the " Marlāva ", consisting of fine sand coloured white, grey, or pink. This is usually followed by a layer of kaolin often mixed with finely divided mica derived from the decomposed rock, and miners affirm that in some localities the " Illama " recurs beneath the " Marlāva ", but usually they reach the rock they term " Pāru gala ", which is said to be chalky in some places and is then known as " Hunu gala ". The composition of this rock has not been determined.

The fossil material obtained was in most cases too scanty for specific or even generic identification, consequently the present paper is but little more than a preliminary record of the occurrence of vertebrate fossils (Mammalia) in Ceylon.



Text-fig. 1.—*Hippopotamus* (*Hexaprotodon*) ? *sivalensis* Falconer et Cautley. Third lower molar, lateral view, × ½.

(1) Elephantoidea.—Dr. Hopwood is of opinion that better specimens might prove that some of the molars belong to *Palaeoloxodon namadicus* (Falconer et Cautley). This elephant is not known south of the Narbadda, and it is possible that in Ceylon it might have developed into a local race, as has the living *Elephas maximus*. If so it might eventually be given a special name. The best fossil of this type is the fragment of a lower molar comprising three lamellae. The crown, which is worn, discloses lateral cusp surfaces which are nearly circular, while the median ones are widened and oval. The enamel is folded on both edges and the cement interspaces are nearly as thick as the enamel plates. The dimensions of this specimen, which will be deposited in the British Museum, are as follows : Greatest depth, 130 mm. ; greatest crown width, 55 mm. ; crown length, 40 mm. ; thickness of a lamella, 16 mm. ; thickness of a cement interspace, 11 mm. ; measured laterally.

(2) Artiodactyla.—(*a*) The most distinctive fossil in the entire collection was the hippopotamus molar. In Asia this animal has evolved a special form which has been placed in the subgenus (*Hexaprotodon*) Falconer, as it possesses six, instead of four, lower

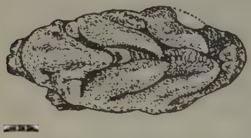
incisors. Until further material is available it is proposed to record the animal as :—

Hippopotamus (*Hexaprotodon*) ? *sivalensis* Falconer et Cautley.

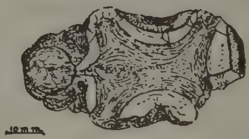
The specimen—an unworn, third lower molar—was obtained from a depth of 30 feet at Kuruvita, near Ratnapura, and is fractured on one side.

The crown comprises two paired cusps between two terminal unpaired ones. All four are connected by a feebly serrate, median ridge, which is narrower than the cusps themselves. The cingulum is moderately defined (Text-fig. 1). The base of the posterior terminal cusp displays two pairs of smaller ones, of which the end ones are vestigial and originate from the base of this cusp, while the other pair are larger and originate from the base of the adjacent paired cusp (Text-fig. 2). Viewed from below only one terminal root is entire, the others are more or less fractured, leaving a large quadrilateral cavity (Text-fig. 3).

In colour the root area is slaty grey, the remainder dark brown. A fracture reveals that the dentine is a chert-like yellow. The specimen, which will be deposited in the British Museum, measures as follows : Maximum diagonal distance from crown to tip of opposite root, 73 mm. ; length of crown 59 mm., greatest external width, 33 mm. ; width across greatest constriction, 14 mm. ; at least constriction, 25 mm. ; depth of tooth above root from 45 to 46 mm.



TEXT-FIG. 2.—*Hippopotamus* (*Hexaprotodon*) ? *sivalensis* Falconer et Cautley. Molar, crown view, × ½.



TEXT-FIG. 3.—*Hippopotamus* (*Hexaprotodon*) ? *sivalensis* Falconer et Cautley. Molar, viewed from below, × ½.

(*b*) Comparison of the bovine cannon bone with that of the water buffalo and with that of the local zebu, which is but little larger than an ordinary half-grown European calf, suggests that this fossil might belong to the now extinct Gaur, which Knox, writing in 1681, recorded from the hill forests of Ceylon. It is proposed to deal more fully with the specimen later. Its length is 210 mm., the width of the shaft is 29 mm.

In conclusion I must express my gratitude to Dr. Hopwood both for his kindness in examining my collection and also for reading over the manuscript of this article ; to Dr. P. E. Pieris, Trade Commissioner (Ceylon), for conveying the fossils to Dr. Hopwood ; and to Mrs. A. H. E. Molamure, Mr. A. H. Nathanielsz, and Mr. Kannangara for supplying me with fossils.

Petrographic Nomenclature.

IN February, 1932, the British Association Committee appointed to examine and report upon petrographic classification and nomenclature issued a questionnaire in the GEOLOGICAL MAGAZINE and in *Science*, in order to ascertain what measure of agreement, if any, exists among petrologists as to the principles upon which a rational system might be established.

An analysis of the results showed that opinion is sharply divided, even upon such fundamental matters as the number of main divisions, whether two or three, into which igneous rocks should be classified. Approximately half the total number of replies received were in favour of recognizing two, the other half, three main divisions. In general, petrologists favouring two divisions would prefer to base them upon textural differences in the rocks, while those favouring three, would base them upon mode of occurrence in the field.

To most members of the Committee it is clear that much of the existing confusion in nomenclature is the result of trying to apply one rock name to specimens from all parts of a rock-body whether lava or intrusion, and regardless of variations in texture and grain-size. As an inevitable consequence, rock specimens strikingly different in appearance are frequently called by the same name; while on the other hand, specimens identical in composition and in all their visible characters bear different names if they have different modes of occurrence in the field. To the teacher of petrology the confusion in the mind of the student arising from this practice is only too familiar. Many, therefore, welcome the tendency, apparent in recent years, to disregard mode of occurrence altogether in questions of nomenclature and to concentrate on the mineralogical and lithological characters of the specimens. This tendency is apparent in the extended use of "rhyolite" to cover very fine-grained acid intrusives as well as lavas, in the application of "basalt" to certain dyke rocks, and of "dolerite" to the coarser portions of some lavas, and in the use of "mugearite" for both Tertiary minor intrusives and lavas of Carboniferous age from the Midland Valley of Scotland. This is a step in the right direction, but the principle has not yet been applied consistently to all rocks: there are still many who maintain that no rock can be correctly named "basalt" unless it occurs as a lava-flow.

Discussion of these facts and of the replies to the questionnaire has led the majority of the members of the Committee to advocate the recognition of three main divisions, to be based upon textural (grain-size) differences, and not upon mode of occurrence. A classification in three divisions based on grain-size will correspond, though only approximately, with the three-fold division based on mode of occurrence, namely lava-flows (rocks of the extrusive phase), minor intrusions (rocks of the dyke phase), and major intrusions (rocks of the major, plutonic, intrusive phase). One must be prepared to find rocks collected from dykes or thin sills (that is hypabyssal) which are identical in all their characters with rocks from lava-flows. Such rocks should have the same name, whether dykes or flows, for there is not sufficient justification for using different names for two rocks identical in all their visible characters. If it is thought to be desirable to imply the mode of occurrence in the name itself, it can be readily done by using the qualifier "intrusive" or "extrusive" as the case may be, before the rock name: thus "intrusive olivine-basalt" is completely informative as regards composition, texture (grain-size), and mode of occurrence.

At the York meeting of the British Association, in 1932, those members of the Committee available decided to examine representative collections of basalts, dolerites, and gabbros, and of granites, granite-porphyries, and rhyolites, and to report upon what divisions could be established upon differences of texture (grain-size) in these two rock series. This work has now been completed and the findings of the Committee are summarized below. The method adopted was to circulate among the members of the Scottish Sub-Committee, comprising Professor E. B. Bailey and Messrs. A. G. MacGregor, G. W. Tyrrell, R. Campbell, and F. Walker, a representative collection of 111 rocks described in Survey Memoirs on Mull, Ardnamurchan, Arran, North Ayrshire, Strath Oykell, Edinburgh, Glencoe, Skye, Golspie, Mid-Argyll, Falmouth, and Camborne. In the Gabbro Series the rocks studied included approximately equal numbers of normal gabbros, fine-grained gabbros, normal dolerites, fine-grained dolerites, normal basalts, and basanites. In the Granite Series the following were included: granite, granodiorite, tonalite, granite-porphyry, quartz-porphyry, granophyre, felsite, microgranite, and rhyolite.

The members of the Sub-Committee reported independently upon each of the 111 slides, and the results were then tabulated and analysed by A. G. MacGregor. In discussion of the results a large measure of agreement was reached upon the principles of a grain-size classification of the two series examined, and a tentative scheme was drawn up embodying these principles. It has now been tested and discussed by other members of the Committee, and it has been decided to publish the scheme and to invite petrologists to test it and communicate their opinion of its usefulness to the Chairman of the Committee, for it is realized that it can be successful only in so far as it meets with general approval, after thorough testing by a large number of petrologists.

THE GABBRO SERIES.

When studying the slides of the basic rock types named above it was found that opinion was unanimous as to the naming of really typical gabbros, dolerites, and basalts. With border-line rocks, however, it was at once evident that to achieve agreement hard and fast limits of grain-size would have to be adopted. For although it was agreed that the coarse-grained specimens were to be called gabbros, those of medium grain, dolerites, and the fine-grained rocks, basalts, each observer had his own independent views on just where "fine" finished and "medium-grained" began, and similarly with regard to the distinction between "medium-grained" and "coarse-grained". It is clear that the personal factor plays far too important a part in the naming of rocks, and to eliminate this factor as far as possible, it was agreed to choose arbitrary limits between the three classes, fine, medium, and coarse. In choosing the limits the Committee were guided by the necessity of using dimensions which could be easily measured, and by the desirability of so choosing them as to cause the least possible disturbance of existing rock names. The limits are so chosen that rocks by common consent called gabbros, dolerites, and basalts respectively, are still so named under the new scheme. As there have been no numerical limits in the past, some adjustment of the names is necessary; but the new scheme is so arranged that the majority of basic lavas of the appropriate mineral composition fall into the Basalt class, the majority of the associated minor intrusives fall into the Dolerite class, and the majority of the major intrusives into the Gabbro class.

The criteria of the Gabbro class apply to the gabbros, olivine-gabbros, eucrites, and norites. The criteria for the Dolerite class apply to dolerites, olivine-dolerites, and quartz-dolerites, while the criteria for the Basalt class apply to basalts, olivine-basalts, and basaltic glass (tachylytes). The classification suggested depends upon the dimensions of the non-porphyritic felspars. For the purposes of the main classification no attention is paid to the dimensions of the ferromagnesian minerals, nor to the dimensions of the phenocrysts (insets), even though these may occupy a volume largely in excess of the matrix in which they are embedded. Further, felspars are ignored when they are isolated from one another in a continuous base forming more than half the entire rock, whether the base be glass or an aggregate of very minute crystals. Such essentially glassy or cryptocrystalline rocks are deemed to fall in the lowest grain-size division of the series. Although there is considerable variation in the mineralogical significance attaching to even common rock names like "gabbro" and "norite", in this report the significance of grain-size in classification is alone considered. It will be sufficiently accurate for present purposes to define gabbro as a coarse-grained igneous rock consisting essentially of monoclinic pyroxene and plagioclase, with or without olivine in addition. The bulk of the felspar occurs in broad crystals with areas in thin section exceeding one square millimeter. When approximately rectangular, as they quite commonly are, the majority of the felspars have a length greater than 2 mm., and a breadth of 0·5 mm., or more, under the suggested scheme. For example, if

Dimensions of majority of quartz and felspars (phenocrysts *not* included) must conform to these limits	GRANITE SERIES			GABBRO SERIES			Dimensions of majority of quartz and felspars (phenocrysts *not* included) must conform to these limits
	Rhyolite	Microgranite	Granite	Gabbro	Dolerite	Basalt	
Maximum area . .	0·0025 sq. mm.	0·25 sq. mm.	⟶	⟵	1 sq. mm.	0·05 sq. mm.	Maximum area
Maximum diameter of roughly equidimensional areas	0·05 mm.	0·5 mm.	⟶	⟵	1 mm.	0·224 mm.[1]	Maximum diameter of roughly equidimensional areas.

In practice it has been found that, in general, the above criteria are satisfied if the length and breadth of crystals conform to the following :—

Maximum length . .	0·1 mm.	0·5 mm.	⟶	⟵	2 mm.	0·5 mm.	Maximum length
Greatest breadth compatible with maximum length . . .	0·025 mm.	0·5 mm.	⟶	⟵	0·5 mm.	0·1 mm.	Greatest breadth compatible with maximum length.

---

[1] $\sqrt{0·05}$ mm ^{2}. Seldom applicable to basalts, which have lath-shaped felspars.

the felspars are rectangular and measure 2·1 mm. by 0·5 mm. the rock is a gabbro.

Dolerites are defined as rocks of gabbroic (mineral) composition of medium grain-size, in which the majority of the felspar laths exceed 0·05 sq. mm. in area, and range upwards to the lower limit for gabbro as above. Thus the laths of felspar in dolerites exceed 0·5 mm. by 0·1 mm. in the finest grained specimens and range up to 2 mm. by 0·5 mm. in those of coarsest grain.

Basalts are rocks of gabbroic composition in which the majority of the felspar laths have areas less than the minimum for dolerite as stated above, that is, have areas of 0·05 sq. mm. or less, the dimensions of the laths of maximum area then being 0·5 mm. by 0·1 mm. Basic rocks containing spherulitic growths to an extent of more than 50 per cent by volume fall into the Basalt class if the breadth of the radial felspars are 0·1 mm. or less, and into the Dolerite class if the breadth lies between 0·1 mm. and 0·5 mm.

Professor Shand has advocated using grain-size to differentiate between his two main divisions, the eucrystalline and the dyscrystalline rocks, drawing the line between them at the limit of unaided vision. This has been borne in mind when fixing the limits of the new scheme, but the Scottish Sub-Committee was unanimous in recommending that the name of a crystalline igneous rock should be based essentially on characters seen under the microscope.

Some members of the Committee at first thought it better to measure the breadth of the felspars, as this dimension in fine-grained rocks may determine whether the felspars are visible or not. On the other hand, it is certainly easier to measure length than breadth accurately, and far easier to estimate the extent to which a felspar lath spans the field of the microscope. In practice, once a few preliminary measurements with an eyepiece micrometer have been carefully made, it is only rarely that recourse has to be made to actual measuring, and eye estimation alone is very often sufficient to place the rock under examination in its correct category. The time occupied in the preliminary measurements is indeed well spent if it results in precision and uniformity of nomenclature.

THE GRANITE SERIES.

It is recommended that for this series the three main classes shall be Granites, Microgranites, and Rhyolites, none of these names to imply special textural characters, but degree of crystallization only, ferromagnesian minerals and all phenocrysts being disregarded.

Granites are the coarsest grained members of the series, and the finest grained rocks to which the name shall be applied should contain felspar and quartz patches which exceed 0·25 sq. mm. in area, and, therefore, have a diameter for equidimensional grains in excess of 0·5 mm.

Microgranites are medium-grained, the upper limit of grain-size being 0·25 sq. mm., while the lower limit must exceed 0·0025 sq. mm.

It follows that the maximum diameter of equidimensional grains is 0·5 mm. while the minimum diameter must exceed 0·05 mm.

Rhyolites include all the fine-grained rocks of granitic composition not covered by the two definitions stated above. The significant figure is 0·0025 sq. mm., which is the maximum area of quartz and felspar patches. Within this area-definition there is scope for the felspar to vary between lath-shaped microlites 0·1 mm. in length by 0·025 mm. in breadth, and equidimensional grains not exceeding 0·05 mm. in diameter.

The term granophyre should be retained as a useful " sack " name, without grain-size significance, for all rocks with graphic or spherulitic intergrowth of quartz and alkali felspar, and with the bulk composition of granites or rhyolites. More precise and preferable names for such rocks are, however, graphic granite, graphic and spherulitic microgranite, and spherulitic rhyolite, according as their grain-size places them in the Granite, Microgranite, or Rhyolite class.

Rocks containing more than 50 per cent by volume of graphically intergrown quartz and felspar are classified as follows : the grouping is determined as usual by limiting areas, calculated in this case from the external dimensions of the majority of individual optically continuous patches of felspar or quartz. When graphic intergrowth constitutes less than 50 per cent of the rock by volume, the classification is based on the grain-size of the predominant felspar and quartz of normal crystallization.

The distinction between " spherulitic microgranites " and " spherulitic rhyolites " is based on the breadth of the individual radially intergrown minerals if the spherulites constitute 50 per cent or more of the rock, but on the grain-size of the minerals in the groundmass if less than 50 per cent. Acid rocks containing spherulites to an extent of more than 50 per cent by volume fall into the Rhyolite class if the breadth of individual intergrown radial minerals is 0·05 mm. or less, and into the Microgranite class if the breadth is between 0·05 mm. and 0·5 mm.

In view of the different interpretations placed upon hyphenated names by different people, it seems best to discontinue using " granite-porphyry ". Rocks previously so called are " porphyritic microgranites " or " porphyritic rhyolites " under the suggested scheme, and correspond to porphyritic granites among coarser grained rocks.

It is considered undesirable to retain " quartz-porphyry " as a systematic rock name, and its place should be taken by " quartz-phyric microgranite " or " quartz-phyric rhyolite " according to its grain-size. Quartz-porphyry may, however, be retained as a useful " sack " name without grain-size significance for acid rocks containing porphyritic quartz.

The essentials of the suggested scheme so far as the Granite and Gabbro rock series are concerned are set out in tabular form p. 322.

It is hoped in due course to publish a complete scheme covering all the igneous rocks; but before proceeding farther it was thought desirable to test public opinion by making the results so far achieved as widely known as possible. Those who have been active in drawing up the scheme are satisfied as to the essential soundness of the principles involved, and as to the usefulness and ease of application of the method. They realize that improvements are not impossible, and ask for criticism after the scheme has been given a fair trial by those interested. Communications should be addressed to the Chairman of the Committee, W. Campbell Smith, British Museum (Natural History), Cromwell Road, London, S.W. 7.

A. K. WELLS,
Secretary of the Committee.

KING'S COLLEGE,
LONDON, W.C. 2.

REVIEWS.

GEOLOGICAL ASPECTS OF UNDERGROUND WATER SUPPLIES. By BERNARD SMITH. Royal Society of Arts, Cantor Lectures, pp. 55, with 16 figs. Published by the Society, John Street, Adelphi, W.C. 2. Price 2*s*. 6*d*.

THE vagaries of the rainfall in the British Isles, as indicated by the floods and droughts of the last six years, have naturally drawn attention to the subject of water-supply in general, both its excesses and its deficiencies. While interest is at present mainly concentrated on the droughts of 1933 to 1935, it should not be forgotten that in 1930–2 parts of the country suffered grievous damage from floods. This shows the uncertainty of the conditions that have to be taken into account.

The Society of Arts has wisely seized the opportunity of publishing in a handy form three Cantor Lectures delivered by the Director of the Geological Survey on "Geological Aspects of Underground Water Supplies". From the great stores of his professional experience and the abundant records and general literature at his command, the Director has compiled an admirable summary of the whole subject, which can be strongly recommended to geologists as well as to general readers, for whom it is no doubt partly intended. Much use is made of the simple conception of the "Artesian Slope", which is so particularly well illustrated by the Lower Greensand under the town of Cambridge; as the author well points out, the general sequence of strata in England from N.W. to S.E. is in effect a succession of artesian slopes. The treatment is by no means confined to the British Isles, many interesting examples being quoted from all parts of the world.

R. H. R.

TERTIARY FAUNAS. A text-book for Oilfield Palaeontologists and students of Geology. By A. MORLEY DAVIES. Vol. I. The Composition of Tertiary Faunas. pp. 406, figs. 565. London: Murby and Co. Price 22*s*. 6*d*.

VOLUME II of this work, which appeared in 1934, has already been noticed in this Magazine (Vol. LXXI, p. 522). The present volume is essentially a systematic palaeontology of the Tertiary period. The Foraminifera, Echinoidea, and Mollusca are treated very fully, but the remaining groups are dealt with very briefly or omitted. While this selection will no doubt meet the requirements of those for whom the work is specially intended, the general palaeontologist would have welcomed an equally full treatment of all the groups of Tertiary fossils—a task no doubt too vast for one author or for one volume. The diagnostic characters of nearly all the genera of the three groups mentioned are given, followed by their distribution and the names of typical species. The numerous line-drawings bring out clearly the characteristic features of the genera. In a few groups, such as the Scutellidae and the Nummulites, it has been possible to give some account of evolution. A very useful feature is the glossary of technical terms given at the end of each group. In using the work we have felt that the classifications adopted would have been more easy to follow if they had been given in outline at the beginning of each group.

The volume is well printed, but would have been more convenient to handle if paper of less weight had been used.

H. W.

INVERTEBRATE PALEONTOLOGY. By W. H. TWENHOFEL and R. R. SHROCK. pp. xvi + 511, with 175 text-figures. McGraw-Hill Publishing Co., New York and London, 1935. Price 30*s*.

THE intention of this work, to provide a readable and well-illustrated account of fossil invertebrates, each section prefaced by a description of the structure of the living animal, is admirable, and the semi-diagrammatic figures (as opposed to mere pictures of fossils) are often well chosen and well drawn. Moreover, there are short sections on oecology, geological history, or stratigraphical range, phylogeny, etc., perhaps scarcely sufficiently detailed, but rightly occupying a subordinate position to the morphological portions. An attempt is thus made to provide in a single volume an elementary text-book covering a wide conception of palaeontology, but whilst the aim is praiseworthy and the book is attractively produced, the result is disappointing and its price (30*s*.) is sufficiently high to place it beyond the reach of most elementary students. Amongst several inaccuracies in the figures, mention must be made of the completely incomprehensible *Monograptus* (Fig. 27k), since this has appeared in at least one other American textbook, and is apparently becoming a standard error.

THE GEOLOGICAL MAP. By K. W. EARLE, pp. vii + 96, with 41 diagrams. Methuen & Co., London. 1936. Price 3*s*. 6*d*.

THOUGH there is little really new in this small book, there are features in it which may assist the student of both geology and geography; the clearly drawn block diagrams should certainly help in the all important principle of " seeing solid " when reading a map, and the brief descriptions of the main features in some representative geological maps, and references to others, should enable the student to study the actual presentation of different geological phenomena on a map. This is all distinctly useful. It is a pity, therefore, that there are some misleading or obscure statements; it seems unfortunate to give the impression on page 2 that bedding planes only separate strata of *different* lithological character, and also that accumulations due to the action of ice and wind are only of recent date; the circumstances described on page 20 would really result in *diachronism* and would never give a section like that shown in Fig. 10; it is certainly high time, too, that the impossible Fig. 28 disappeared from all text-books in which Rift faulting is ascribed to the collapse of the ground between the faults. In a book of this kind, too, it would be well to have given some idea of the different *scales* of folding as commonly implied in the terms " recumbent " and " isoclinal ", which are, of course, far from being one and the same thing; and the sentence that " a fault plane may have any direction whatsoever and any disposition " conveys an idea of haphazardness in faulting that must, we feel sure, be very far from the author's intention.

We think he is mistaken in what he considers to be the three factors of importance in reading any geological map, for he entirely omits the *strike*; surely the important factors should be: the surface relief, the *strike* from which the dip may be found, and hence the superposition of the strata and all structural details deduced.

G. L. E.

THE MESOLITHIC SETTLEMENT OF NORTHERN EUROPE. By J. G. D. CLARK. Cambridge University Press. 10 + 7½ in., xvi and 284 pp., vii plates and map in folder at end. Price 25*s*. net.

THE sub-title of the book is " A Study of the Food-Gathering Peoples of Northern Europe during the Early Post-Glacial Period ".

It is a little surprising, therefore, to find that it includes a considerable amount of interesting geological information in the first chapter (54 pp.). The author suggests the contemporaneity of the Baltic end-moraine and the Bühl stadium of the Alps. He outlines the principles of De Geer's geochronological studies and tends to accept the alleged world-wide synchronization: the pitfalls of the method might have been stated, as they are by De Geer himself.

The section on changes in the mutual relations of land and sea is too brief to be useful to geologists, and the problems are rather lightly treated: some would not agree that the isostatic theory is simple.

A brief summary of the changes in the Baltic is given: much of the information was available before the War in W. B. Wright's *Quaternary Ice Age*, but its restatement is useful.

The author then develops the argument of his book and explains the value of pollen-analyses. He turns to climate, fauna, and flora and there is much information that is difficult to obtain elsewhere.

The main body of the book is given to the industries—Maglemose, microlithic, etc.—and the material is well and clearly illustrated. There are seven appendices: the first is a valuable faunal list, well arranged, detailed, comprehensive, and presumably accurate, which will be invaluable and widely welcomed. Appendix V is a summary of the pollen analyses.

The book contains a great deal of information that was in need of being brought together in this way and the author is to be congratulated on the success with which he has handled "border-line subjects" in that difficult field between geology and archæology.

The use of modern botanical methods for archaeological purposes is welcome and the results gratifying. The book is profusely illustrated and beautifully produced, and the price must therefore be at a level that may discourage students who would be well advised to buy it.

K. S. S.

REPORTS AND PROCEEDINGS.

Mineralogical Society

25th June, 1936.

Mr. M. H. Hey exhibited a model of the crystal structure of eddingtonite, together with a specially designed platform used in constructing the model.

(1) "The Paragenesis of Kyanite-eclogites." By Professor C. E. Tilley.

The composition of pyroxenes from eclogites is correlated with that of their associated garnets. The chemistry of kyanite-bearing eclogites and the genetic significance of their contained kyanite is discussed in the light of this relation.

(2) "The Tenham (Queensland) Meteoritic Shower of 1879 (or 1869?)." By Dr. L. J. Spencer.

Very little information can now be gathered about a remarkable shower of meteoric stones that fell in south-west Queensland in 1879 (or 1869?). But a tangible piece of evidence has recently been supplied by the acquisition for the British Museum collection of meteorites of a fine series of 102 complete stones with a total weight of 107¾ lb. This is the best example of a meteoritic shower to be seen in the collection. The stones, ranging in weight from 5,245 grams (11½ lb.) to 17·5 grams, were collected over a track extending 41 miles west to east near Tenham station in the Gregory South district, and they had long remained in private hands. An unpublished chemical analysis, made in 1913 in the Government Chemical Laboratory at Brisbane, shows a striking similarity in composition to the Baroti (India, fell 1910) meteoric stone. Showers of meteoric stones have evidently been produced by the breaking up of a single large mass of friable material in the earth's atmosphere.

(3) "Some Unusual Twin-laws observed in Potash-felspars from Goodsprings, Nevada, U.S.A." By Dr. J. L. E. Drugman.

This locality is unique for fine, sharply defined felspars and the object of this preliminary note is to show the general possibilities of the occurrence for the confirmation of rare or new laws. Besides unusual variants in habit of the Manebach and Baveno laws, examples of other rarer laws and, possibly, new ones will be shown, e.g. twinning on face $(\bar{1}12)$, on axis $[\bar{1}12]$ and on [110), and on ?$(\bar{3}02)$.

CORRESPONDENCE.

THE PURBECK FAULT.

Sir,—Dr. Arkell is to be congratulated on publicly challenging the very possibility of the section at Ballard Head being due to an overthrust from the north. I have many times cudgelled my brains both on the spot and away from it to find any sequence of events mechanically possible which would admit of the slightest overthrust from the north to wind them up and leave such a section. But the considerations that always finally defeated my efforts seem to be equally fatal to Dr. Arkell's alternative proposal. For the whole length of Studland Bay the chalk is of very uniform character, firm and standing well in large blocks, but never hard and always readily sectile. This seems almost impossible in chalk through which has been transmitted a powerful horizontal thrust against an enormously massive and hard "horst": and I am not sure that it is not more improbable in chalk that has had a series of bendings to and fro passed through it as postulated by Dr. Arkell's theory. Now chalk which has gone through such an experience *might* afterwards be reconsolidated with its original character; but such an explanation is ruled out by the impossibility that such delicate and brittle fossils as *Crania*, or spines of *Cidaris*, or branching Polyzoa, which occur very consistently in great perfection, could have survived such an experience or be reconstructed after the inevitable splintering. The only direction in which I see any hope is in a theory which provides a final stage in which the fault which has preserved the chalk which supports the Tertiaries and emerges from beneath them to the north on the Puddletown-Bere line, from being involved in the upthrust to the south, shall open sufficiently to allow the approximately horizontal chalk to the north to sink slightly and have its edges caught up along the fault. For the chalk north of the fault to retain so far its original character the gentlest form of bending, which is sagging, should be invoked.

A noticeable assertion by Dr. Arkell is that where the fault reaches the foot of the cliff the chalk south of, or below, it is younger than that north of or above it. Has he any evidence to support this relative dating? It is a point of cardinal importance, if it can be established.

A very great difficulty in this case is to remember constantly that the cliff line in Studland Bay is broadly parallel to the Purbeck fault, not at right angles to it, and therefore nowhere at any great distance from it, and that any dip visible in Studland Bay is mainly, if not wholly, attributable to the system of very broad undulations : with north and south axes, which carry the gently synclinal chalk underlying the Tertiaries out of sight between Corfe and Lulworth, and then bring it up to a very considerable height about Lulworth. In this latter block the chalk appears to be practically horizontal, the chalk around Wool not yielding *Magas pumilus* so far as is known and being therefore basal *mucronata* and that of Coombe Keynes and the edge of Lulworth Park yielding *Magas pumilus* but not much variety or abundance of other fossils and being apparently "lower *mucronata*" of Spencer while that on the high ground above Lulworth yields *Magas pumilus* with a variety of other fossils comparable with those of the chalk of Studland Bay, which is "middle *mucronata*" of Spencer, and being perhaps even somewhat richer and therefore presumably younger than the latter chalk. It would be very interesting to know if this chalk bends up sharply on approaching the Purbeck fault, as is strongly suggested by the behaviour of the *quadratus* chalk in Bat's Head.

R. M. Brydone.

12c Upper Montagu Street,
London, W. 1.
21st May, 1936.

THE GEOLOGY OF KAVIRONDO.

Sir,—In his paper on "The Geology of an Area in the Kavirondo District, Kenya Colony" (*Geol. Mag.*, January, 1936), Dr. Pulfrey says :—

"Previous to 1931 the Kakamega area, in the Central Kavirondo Reserve of Western Kenya, was almost unknown from a geological standpoint. Gregory had made brief references to it, but no detailed geological or petrographical examinations had been made of any part. Following on the discovery there in 1931 of alluvial and reef gold, and subsequently the entry of mining companies into the field, a great deal of geological research has been carried out."

It seems strange that Dr. Pulfrey should have overlooked the pioneer work of Combe, whose report and map laid the foundations of the geology and petrology of the area ; for although the full report and map were not printed, they were lodged in the Kenya Secretariat (and subsequently in the Mines Office ?), Nairobi, so that all official geologists have had access to them, and condensed statements, by Combe, giving a fair amount of detail were published several years before 1931. The references are :—

(1) " Kavirondo, Kenya," *Ann. Rept. Geol. Surv. Uganda* for 1927, p. 15.
(2) " Kavirondo, Kenya," *ibid.*, for 1928, p. 9.
(3) " The Green-Grey Rocks of North Kavirondo," *ibid.*, for 1929, p. 18.

At the end of the second of the publications listed above the following will be found :—

" In a further search for mineral deposits, the belt of intruded rocks of the Karagwe-Ankolean System along the edge of the Maseno intrusion should be prospected in an easterly direction adjacent to the Edzawa River in Northern Maragoli and Nyangori."

This advice was taken and resulted, as is now widely known, in the discovery of the Kakamega goldfield.

With regard to works relevant in this connection published after 1931 but before the appearance of Dr. Pulfrey's paper under reference, but not therein referred to, the following should be noted :—

" The North Kavirondo Area," by A. D. Combe, *Mem. II Geol. Surv. Uganda* (" The Geology of South-West Ankole . . ."), Appendix II (" The Distribution of the Rocks of the Karagwe-Ankolean System "), 1932, p. 218.

" A Contribution to the Study of the Geology of Kavirondo," by K. A. Davies, *Bull. No.* 2, *Geol. Surv. Uganda*, 1935, p. 30.

E. J. Wayland.

Geological Survey Office,
Entebbe, Uganda.
27th March, 1936.

THE BASAL COMPLEX IN JAMAICA.—A REPLY.

Sir,—I have read with much interest Dr. C. T. Trechmann's paper in the June number (pp. 251–267) on the Basal Complex in Jamaica. As he takes a quite different view of the age of the Jamaica schists and granodiorite from that expressed in my 1929 paper (*Q.J.G.S.*, lxxxv, 440–492) I wish to say at once that I am not convinced by the evidence, particularly as to the age of the granodiorite, which he asserts to be intrusive into the Tertiary "White Limestone" and to be not earlier than Oligocene in age. The acceptance of his interpretations of the exposures that he describes would still leave us with a body of other evidence which cannot be reconciled with his conclusions. Unfortunately, I am much handicapped in discussing his paper, because the described exposures are some 4,000 miles away and personal examination of them cannot be made.

It is a pity that the author has not fortified his evidence by a petrological description of some of the more important rocks he mentions, but in his paper he has generously offered to allow an investigation of his rock-specimens by anyone interested, an offer of which I intend to avail myself, and, as I am at present preparing a detailed account of the geology of the Kingston District for the Geological Society of London, I hope to include a discussion of his views in it after I have studied his specimens.

Meanwhile, I will comment on his interpretation of two of the sections described in his paper. On page 259 he describes the junction of the granodiorite with the Purple Conglomerate in the River Wagwater as an intrusion, whereas I have mapped it as a high-angled thrust traceable for some miles. As the Purple Conglomerate itself contains, in places, an abundance of granodiorite pebbles identical in character with the plutonic rock—I can supply Dr. Trechmann with precise localities where they can be found—it is very unlikely that the granodiorite is intrusive into this formation. In his account the author states that the conglomerate is "crushed to a green and purple mass for several feet away from the granite" and that a little farther away it is normal and uncrushed. This local crushing at the junction supports the view that my mapping of the boundary as a thrust is correct, and, in the absence of any photograph or sketch of the exposure, I suggest to the author that he might consider whether the granitic material in the crushed conglomerate at the junction might not have been torn out of the granodiorite along the zone of thrusting.

Another piece of evidence adduced by the author is the supposed thermal alteration of the White Limestone in Green Bay below the Lazaretto (p. 261). It is unfortunate that he failed to find the well foliated green hornblende-schists and amphibolites which occur on the road at a higher level than the Lazaretto itself. These schists lie immediately under the limestone in the core of an anticline or dome, and microscopic examination by Mr. Higham (page 486 of our paper) showed that they bear traces of an older foliation which is crossed by newer, more dominant planes. They also furnish evidence of movement at a still later period when the rock was fractured and the thread-like fissures filled with quartz. These schists are similar to the green Westphalia Schists of the Complex, about 18 miles away, where they are associated with other altered rocks, including marbles.

But although the author did not see these schists he discovered the very interesting section in the cliff below the Lazaretto shown in his text-fig. 3. The succession there is read by him as (4) normal White Limestone underlain by (3) a few inches of friable broken-up yellowish dolomitized limestone, which in its turn overlies (2) a grey and streaky or white marble 1–2 feet thick. This marble passes down into (1) a " hornfelsed and darkened limestone, veined and fractured ". The author considers that all these beds belong to the White Limestone formation, and that the lower beds have been thermally metamorphosed by " probably some intrusion not far away ". On the other hand, my own interpretation of his text-figure is that the base of the White Limestone should be drawn below the few inches of dolomitized limestone, and that the marble and hornfelsed beds below it are members of the Basal Complex on which the limestone rests unconformably, as it does on the hornblende-schists near by.

How otherwise is the presence of the hornblende-schists to be explained ? The White Limestone in this area forms a gentle dome with dips of 25° to 30°, and has never been subjected to severe earth-movement, yet in the core of the dome immediately underlying the normal limestone we find thoroughly foliated schists which give evidence of two periods of dynamo-metamorphism and a much longer geological history.

I consider that the author has failed to prove his case for the Tertiary age of the granodiorite, and, in my opinion, can never hope to do so. He himself notes (p. 263) that the White Limestone can be found within a few inches of this great plutonic mass with no more change than a little dolomitization, although there is a wide zone of hornfelsing not far away. He offers the explanation (without giving any proof) that the hornfelsed rocks have fallen into or become pendent in the granodiorite, while the unaltered limestone is " at the outer contact " ! My own view is of course that the plutonic rock was already unroofed when the White Limestone was deposited and that both it and the hornfelsed beds are of much earlier age and are part of the Basal Complex.

C. A. MATLEY.

10 MILVERTON TERRACE,
LEAMINGTON SPA.
5th June, 1936.

NOMENCLATURE OF CONGLOMERATES.

SIR,—In a study entitled " An attempt at the Correlation of the Ancient Schistose Formations of Peninsular India ", the first part of which is now in the press (*Memoirs Geological Survey of India*, lxx), I have had occasion to discuss the nomenclature of conglomerates, and as this may prove of interest to the readers of your journal, I send you herewith enclosed the copy of a passage which appears as a footnote.

L. L. Fermor.

Geological Survey of India,
Calcutta.

Copy of footnote on page 10 of *Memoirs G.S.I.*, lxx, part i :—

"I propose as far as possible to avoid the use of the terms autoclastic and epiclastic, for obviously they are unfortunate as at present applied. On the analogy of the use of the terms 'syngenetic' and 'epigenetic' as applied to ore deposits, usages which appear happy, the term *synclastic* should be applied only to a sedimentary conglomerate, as the clastic character of the pebbles was produced contemporaneously with the clastic character of the associated sand and clay, and the pebbles were deposited contemporaneously with the associated sand and clay ; similarly the term '*epiclastic*' should be applied only to a conglomerate in which the clastic character has been superposed on the rock subsequent to its formation, i.e. to crush-conglomerates. The term *autoclastic* should be applied to rocks in which the clastic character has been produced by the rock itself. It is difficult to imagine the process by which this might happen, but perhaps flow-breccias may be regarded as autoclastic breccias because they are formed by the flow of a portion of the rock itself. A crush-conglomerate is obviously not an autoclastic one."

AMMONITE TERMINOLOGY.

Sir,—In Part II of my work on the Upper Jurassic Invertebrate Faunas of Cape Leslie, Milne Land (*Medd. om Grönland*, vol. 99, No. 3) recently published, I proposed the new genus *Kochina* for a group of ammonites with *K. groenlandica* nov. as genotype. Unfortunately the generic name is preoccupied (C. E. Resser, 1935), as Mr. Alfred Rosenkrantz of Copenhagen kindly informs me, and I therefore propose to substitute for *Kochina* (Spath *non* Resser) the new name *Laugeites*, gen. nov. the genotype remaining *L. groenlandica* (Spath).

L. F. Spath.

THE NEWRY IGNEOUS COMPLEX.

Sir,—In a *Memorandum* on an excursion to the Newry Igneous Complex, published in your June number, Professor E. B. Bailey records certain conclusions which differ from those reached by Miss Doris Reynolds. The closing sentence reads as follows : "In writing this memorandum, I have not consulted other members of the party, but I am sure from discussion during the excursion that most of them have come to similar conclusions." While it is true that scientific progress depends on evidence and not on votes, it seems to me that this attempt to influence opinion by invoking weight of numbers is unfair in that it involves reputations as well as hypotheses. I have therefore ascertained the facts by communicating with the members of the party—other than Professor Bailey himself and one member who is abroad. It turns out that it is not true "that most of them have come to similar conclusions".

In a recent article on "The Idea of Contrasted Differentiation" (GEOL. MAG., 1936, pp. 228–238), I have already given reasons for differing from Professor Bailey in the field of petrogenesis. Fortunately I need not enter into the technical details of the additional points raised in the *Memorandum*, since Miss Reynolds has clearly presented a host of relevant facts (in press, GEOL. MAG., 1936), which, to my mind, effectively dispose of the criticisms offered. I wish, however, to place on record that since Miss Reynolds completed her field work on the eastern end of the Newry Complex, I have spent nearly three weeks on the ground, and examined all the thin sections that have been cut, as a result of which I am in entire agreement with her statement of the evidence, and with the straightforward and objective interpretation of that evidence which she has given.

Dr. Alfred Brammall, who collected critical specimens from the Newry Complex, and has since examined them—particularly for evidence of the syntectic processes postulated by Miss Reynolds, has invited me to add that he, too, is in entire agreement with her interpretation.

ARTHUR HOLMES,
University of Durham.

SCIENCE LABORATORIES,
SOUTH ROAD,
DURHAM.
18th June, 1936.

ON BABABUDANITE.

SIR,—I have read the letter of Mr. B. Rama Rao in the April number of the GEOLOGICAL MAGAZINE, and though reluctant to take up space on a matter of somewhat local importance, I consider it necessary to correct certain wrong impressions that this letter gives.

Mr. Rama Rao's letter would seem to suggest that I was not aware of Jayaram's statement that bababudanite was probably a secondary metamorphic mineral. I have discussed this matter elsewhere [1] and so shall content myself here by stating that Jayaram's was a mere suggestion unsupported by either field or microscope evidence. I submit that mine remains the only detailed work [1] on the Bababudan area which has clearly shown the secondary nature of this mineral.

---

[1] *Current Science*, iii, 1935, 608.

I am more than surprised, however, at the latter part of Mr. Rama Rao's letter where he states that the "ferruginous amphiboles have been long regarded in Mysore as secondary minerals of metamorphic origin". If this were the case, why did Mr. Rama Rao himself, as recently as 1934, write as follows in regard to cummingtonite? "A reference to the previous publications of the Mysore Geological Department on the genesis of this mineral indicates that in *all the recorded instances* it has been considered as the *original* remnant constituent of a cummingtonite rock, due to the breaking down of which many of the 'ferruginous quartzites' of Mysore are believed to have been formed," [2] and again, "contrary to the *usually accepted view* of the *original* character of the mineral in Mysore. . . ." [3] (Italics mine.)

The history of these ferruginous amphiboles in Mysore is intimately connected with that of the iron formations, and it is significant that as late as 1932, Mr. Sampat Iyengar, who was then the Director of Geology in Mysore, attributed the formation of ferruginous quartzites to the metasomatic alteration of original cummingtonite schists.[4] Again, in 1934, the authors of a Mysore Geological Department Bulletin state that "cummingtonite schist has altered into ferruginous quartzite".[5] I could give more instances, if need be, to prove that the Department (except for stray observations), never seriously countenanced the secondary character of these amphiboles till 1934, that is, a year after I had pointed out the metamorphic development of both bababudanite and cummingtonite in the banded ferruginous quartzites of the Bababudan Hills.[6]

C. S. PICHAMUTHU.

UNIVERSITY OF MYSORE,
BANGALORE.
23rd April, 1936.

---

[1] *Half-Yearly Journ. Mysore Univ.*, viii, 1935.
[2] *Mysore Geol. Dept. Bulletin*, No. 15, 1934, 23–34.
[3] Ibid., 33.
[4] *Rec. Mys. Geol. Dept.*, xxx, 1932, 15.
[5] *Mys. Geol. Dept. Bulletin*, No. 14, 1934, 11.
[6] *Current Science*, i, 1933, 276–7.

THE

GEOLOGICAL MAGAZINE

VOLUME LXXIII.

No. VIII.—AUGUST, 1936.

ORIGINAL ARTICLES.

The Two Monzonitic Series of the Newry Complex.

By Doris L. Reynolds, The University, Durham.

(PLATE V.)

I. Introduction.
II. Olivine-monzonite.
III. Syenite.
IV. Crystalloblastic Textures.
V. The Two Monzonitic Series and their Relationships.
VI. Comparison with Other Areas.
VII. Interpretations :—
  (*a*) Mobilized Sediment.
  (*b*) The Two Monzonitic Series.
Appendix: Reply to Professor E. B. Bailey.

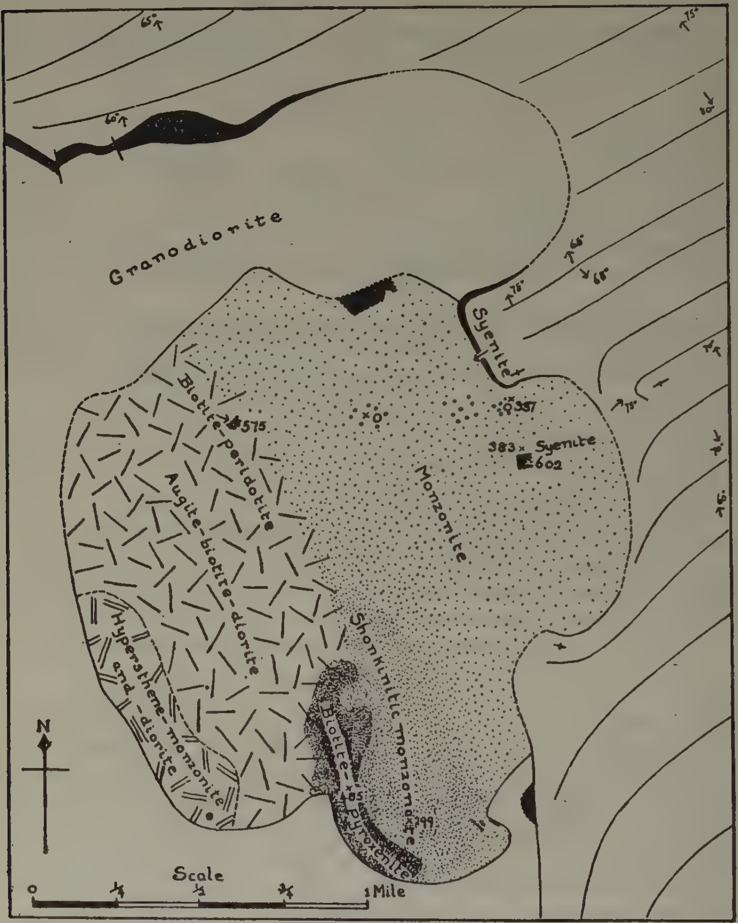
I. Introduction.

In a study of the rocks of the eastern end of the Newry Complex,[1] the writer distinguished two contrasted groups of hybrid rocks—(i) the *Slievegarron* type, and (ii) the *Seeconnell* type—both of which are intimately associated with biotite-pyroxenite and biotite-peridotite. The Slievegarron hybrids comprise an augite-biotite-diorite series. The typical augite-biotite-diorite (1934, p. 611) is a highly undersaturated rock heteromorphous with certain varieties of orthoclase-basalt and leucite-basanite; it might equally well be described as biotite-essexite-gabbro. No further discussion of these rocks will be undertaken in this paper, but it seems desirable to point out that they should not be confused—as unfortunately they have been—with gabbro-diorite.

The present contribution is mainly devoted to the Seeconnell hybrids, which are dominantly monzonitic. Over most of the area characterized by Seeconnell types the rocks are related to the biotite-pyroxenite. This relationship is evidenced (*a*) in the field, in that there is gradation from biotite-pyroxenite, through shonkinitic monzonite, to monzonite and syenite (see Fig. 1); and (*b*) mineralogically, in that diopside, similar to that in the biotite-pyroxenite, occurs throughout the Seeconnell suite, whilst large

---

[1] D. L. Reynolds, "The Eastern End of the Newry Igneous Complex," *Quart. Journ. Geol. Soc.*, 1934, **90**, 585–636. Further references to this paper are made by year and pages only.



TEXT-FIG. 1.—NORTH-EASTERN CORNER OF THE NEWRY IGNEOUS COMPLEX. Outcrops of mobilized sediment are shown in black. The structure of the Silurian sediments is indicated by strike lines and dips. The heavy dots to the east of the biotite-peridotite indicate occurrences of monzonite found in thin section to be mineralogically related to the biotite-peridotite. The two localities where olivine is present in such types are marked 0. The numbers refer to the analysed rock specimens.

flakes of biotite of biotite-pyroxenite type are present in the more melanocratic Seeconnell rocks.

Due east of the small exposure of biotite-peridotite, however, the Seeconnell hybrids are characterized by a pinkish augite and a biotite of amber to foxy-brown colour, both of which resemble the corresponding minerals in the biotite-peridotite. At two localities such rocks were found to contain olivine (see Fig. 1). On mineralogical grounds, therefore, they were regarded as being related to the biotite-peridotite rather than to the biotite-pyroxenite (1934, p. 618).

The combined evidence of mineralogy and field distribution thus points to the existence, in the hybrids of Seeconnell type, of two analogous rock-series which converge towards syenite :—

Biotite-pyroxenite — shonkinitic monzonite — monzonite ——— syenite
Biotite-peridotite ——————— olivine-monzonite ———

When the 1934 paper was published only three members of the two series had been analysed. Since then, two other types, olivine-monzonite and syenite, have also been analysed. The main purpose of the present paper is to record these new analyses ; to describe the analysed specimens ; and to establish the two converging monzonitic series and their relationships, on a chemical basis. For brevity the two series may be referred to as the biotite-pyroxenite and biotite-peridotite series.

II. Olivine-Monzonite.

The chemical composition, norm, and mode of the analysed olivine-monzonite, No. 337, from Slievenisky (for exact locality see Fig. 1) are listed under D in Tables I and II.

The texture of the olivine-monzonite is characteristically crystalloblastic, as will be apparent from the descriptions of the individual minerals given below.

Augite, the most abundant ferromagnesian constituent, forms large crystals which reach a size of about 3 by 2 mm. It is pinkish in colour and resembles the augite in the biotite-peridotite (1934, p. 604). $Z \wedge c = 45^\circ$. Although showing a tendency to develop faces in the prism zone, the crystals have characteristically irregular outlines, with curved re-entrants and slender outgrowths. Outlying portions of augite, though completely isolated in the leucocratic matrix, are commonly found to be optically continuous with a neighbouring crystal. Such outlying portions vary in size down to forms of such extreme delicacy that they are visible only under high magnification. In the *camera lucida* drawing, Fig. 2, an augite is shown which has outlying portions not only in the leucocratic matrix, but also in a neighbouring augite. Such textures constitute indubitable evidence of crystalloblastic development. Moreover, the augite frequently exhibits sieve texture, the sieves being filled with felspathic material similar to that of the matrix.

Biotite, frequently developed around iron ore, the outline of which it follows, builds flakes up to 2·5 mm. across. It is amber to foxy brown in colour, similar to the mica in the biotite-peridotite, but in contrast with the duller brown variety which characterizes the melanocratic rocks of the biotite-pyroxenite series. Like the augite, it is crystalloblastic in its development: irregular neighbouring portions, isolated in the leucocratic matrix, being optically continuous. Moreover, the biotite frequently shows fringe-like dactylitic outgrowths which cut across the boundaries of the felspathic elements of the matrix. In these outgrowths the biotite sometimes passes to a green variety.

Olivine occurs in relatively large crystals or glomeroporphyritic groups (up to 3 by 2 mm.) which are widely dispersed so that, as shown in the mode, it makes up but 3 per cent of the rock. It resembles the olivine of the biotite-peridotite (1934, p. 604) in being optically negative and showing an almost straight isogyre in β sections. It is surrounded by a narrow corona structure composed of an inner zone of rhombic pyroxene and an outer zone of fibrous biotite, the latter varying in colour from brown to green. Colourless needles which show oblique extinction, and are probably pyroxene, traverse the biotite and extend beyond it. The fibres and needles of biotite and pyroxene alike penetrate the leucocratic matrix, cutting clean through from one felspar crystal to another. The corona structure is, therefore, crystalloblastic and has developed later than the matrix felspar. The olivine exhibits various stages of alteration to serpentine. Some examples are completely pseudomorphed, and in these cases also the corona structure is present.

Felsic Constituents.—The leucocratic portion of the rock consists of andesine (about Ab_{67}), which is sometimes zoned, together with an optically negative soda-potash felspar. The latter is usually untwinned, but occasionally exhibits exceedingly fine twin lamination, with nearly straight extinction. The plagioclase occurs as relatively large crystals and groups of crystals. Although there is some approximation towards roughly rectangular outlines, the crystals have exceedingly crenulate margins, with delicate protuberances and isolated, but optically continuous, outlying portions. The latter are enclosed by alkali felspar and plagioclase alike. Indeed, the plagioclase closely resembles the augite in the peculiarities of its development and, like it, is typically crystalloblastic.

The alkali felspar, which forms a matrix to the other minerals, is extremely irregular in outline: neighbouring individuals being intergrown in an intricate manner, reminiscent of a highly complex jig-saw puzzle. Again, isolated portions are optically continuous. The alkali felspar is riddled with exceedingly fine vermicular quartz. From the presence of round blebs, representing cross-sections, the form of the quartz vermicules is inferred to be tubular; the terminations are generally blunt or bulbous. The vermicules average about ·005 mm. across and are too fine to interrupt the interference colours or extinction of the felspar (see Plate V). Their identification as quartz rests in the refractive index, which is slightly higher than that of canada balsam, and in the fact that they are not attacked by hydrochloric acid. By altering the focus of the microscope, the quartz vermicules can be observed at various levels in the alkali felspar. They sometimes cross the boundaries between adjacent felspars. Neighbouring vermicules may be arranged in sub-parallel or fan-like groups; branched forms occur here and there. The vermicular quartz has not been observed traversing the plagioclase, but not infrequently it penetrates the marginal zone of the augite and enters the biotite. In the latter it sometimes reaches the interior, where it spreads out like a malignant growth. The symplectite of vermicular quartz with felspar is clearly a myrmekite-like structure.[1] It is characteristic of much of the rock on the eastern side of Slievenisky and was briefly mentioned in the 1934 paper (p. 616).

Taking into account the actual amounts of biotite and olivine in the mode of the olivine-monzonite, and comparing these with the normative composition, it can easily be calculated that the quantity of free quartz in the rock is of the order 2·2 per cent.

Professor E. B. Bailey, who has examined sections of some of the monzonites, including a slide of the olivine-monzonite here described, writes [2] as follows: "Many of the augite-monzonite suite, even where they contain fresh olivine, also contain abundant micropegmatite. This has been called myrmekite by Miss Reynolds, though I do not quite like the name, as the material does not resemble closely the myrmekite with which I am familiar in Scotland. One olivine-rich slice may be taken as a type. The olivine is mostly fresh, though encased in reaction products. The micropegmatite is so abundant that it is inconceivable that its material was present when the olivine crystallized. One finds therefore conclusive evidence of migration of early crystals relative to melt (presumably residual melt)."

In connection with these remarks it should be noted that the "olivine-rich slice" is that under description No. 337. Whether or not it is preferable to describe the symplectite (see Plate V) as myrmekite or micropegmatite, the fact remains that the rock contains about 2·2 per cent of quartz, which hardly corresponds to "abundant micropegmatite". Moreover, a slice with only 3 per cent of olivine cannot properly be described as "olivine-rich". Reference to the norm (D in Table II) shows the rock to be undersaturated, the quantity of normative olivine being of a similar order to that actually present in the rock. Obviously the association of olivine and quartz in the amounts present is in no way abnormal, whether the olivine crystallized from a melt having the composition of the actual rock or whether it represents a result of metasomatic introductions. An interpretation on the latter lines is offered towards the end of this paper (see page 358 et seq.).

The plagioclase is clouded with fine dust-like inclusions, amongst which fine rods of an opaque mineral, possibly iron ore, can be distinguished. It also contains blebs of biotite. The clouding is patchy in distribution and follows the direction of the twin lamellae, parallel to which the minute rods are also orientated. The microlites resemble those which characterize many basic igneous rocks, as noted by Gillson.[1] The symplectite of alkali felspar and quartz exhibits a similar clouding, but here the material is much coarser and amongst the dust-like inclusions there are fine rods and hair-like growths which penetrate quartz and felspar alike (see Plate V). The rods sometimes maintain their direction on passing from plagioclase into the quartz-felspar symplectite where, however, they become coarser. Blebs of biotite also attain a larger size in the alkali felspar than in the plagioclase. The opaque rods with which the symplectite is clouded can also be seen, though rarely, to continue into the biotite. The facts—(*a*) that the swarms of minute rods occur in plagioclase and alkali felspar alike, and sometimes maintain their direction in passing from one to another; (*b*) that individual rods in the alkali felspar cut across successive quartz vermicules; and (*c*) that the rods can also be found, though rarely, in the biotite—indicate that the clouding is due to migration of material after the felspars, quartz-felspar symplectite, and biotite had completed their growth.

---

[1] J. J. Sederholm, *Bull. Géol. Comm. Finlande*, **48,** 1916.

[2] E. B. Bailey, "Memorandum" *re* Newry Igneous Complex, GEOL. MAG., LXXIII, 1936, 270.

The clouding of the plagioclase is regarded by Professor Bailey (1936, p. 270) as evidence that the monzonitic rocks have suffered contact metamorphism (i.e. baking). The only later intrusion to which such metamorphism could be referred is the granodiorite of the area.[2] It is, however, impossible to correlate clouding with contact metamorphism by the granodiorite, for the following reasons :—

(*a*) Clouding in the monzonitic rocks does not become more conspicuous as the granodiorite is approached, but is equally well developed towards the sedimentary contact, i.e. away from the granodiorite.

(*b*) In the augite-biotite-diorite, which is also cut by the granodiorite, clouding of the plagioclase is not characteristically developed.

In his discussion of clouding phenomena in plagioclase, MacGregor[3] has not overlooked the hypothesis that clouding may sometimes be due to autopneumatolysis. Presumably, therefore, it may equally well be considered as due to pneumatolysis without the theoretical limitation implied by the prefix *auto.* Such pneumatolysis in the Seeconnell hybrids is only a minor detail of the whole complex process whereby the hybrids themselves are believed to have been formed—a process of the nature of pyrometasomatism, which is further discussed on page 359.

Accessories.—Iron ore occurs in irregular masses, many of which are surrounded by biotite. Large crystals of apatite occur in both the felsic and the mafic portions of the rock. Minute needle-like crystals of apatite penetrate the leucocratic constituents.

III. SYENITE.

The chemical composition, norm, and mode of the analysed syenite, No. 383, from Slievenisky (for exact locality see Text-fig. 1) are listed under E in Tables I and II.

---

[1] J. L. Gillson, *U.S.G.S. Prof. Paper* **158** D, 1929, 80.

[2] In case the implication of this statement is not clear, it should be emphasized that the augite-biotite-diorite is not a later intrusion, but is gradational to the biotite-pyroxenite—monzonite and biotite-peridotite—monzonite series.

[3] A. G. MacGregor, *Min. Mag.*, **22**, 1931, 524–538.

Though variable in texture, the syenite is always crystalloblastic. The analysed specimen, which is described below, is a fair average of the hornblendic variety. The latter grades to a variety in which augite is of more frequent occurrence.

TABLE I.

	A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*
SiO_2	45·91	41·71	53·10	55·20	56·52	66·65	68·80
Al_2O_3	3·51	8·55	14·52	15·30	18·30	14·33	14·15
Fe_2O_3	2·11	2·51	0·86	0·68	1·50	0·55	0·50
FeO	9·73	9·79	6·40	5·76	4·29	5·62	5·03
MgO	19·42	14·65	6·71	5·20	2·23	3·00	2·39
CaO	14·28	11·74	6·78	6·50	3·62	1·47	1·20
Na_2O	0·31	0·60	2·99	3·02	4·47	2·49	1·62
K_2O	0·58	3·65	4·82	4·80	5·79	2·99	1·97
$H_2O +$	1·42	1·41	1·00	0·50	0·71	1·82	2·95
$H_2O -$	0·11	0·16	0·06	0·30	0·08	0·13	0·23
CO_2	0·45	0·16	0·02	none	none	none	none
TiO_2	0·72	2·15	1·09	1·66	1·11	0·92	0·87
P_2O_5	1·00	1·62	0·83	0·72	0·80	0·17	0·18
Cl	0·02	0·01	0·04	n.d.	0·03	0·02	n.d.
F	n.d.	0·16	0·07	n.d.	n.d.	n.d.	n.d.
S	tr.	0·03	none	n.d.	none	tr.	tr.
Cr_2O_3	0·10	0·04	0·03	n.d.	none	0·01	0·01
V_2O_3	0·03	0·06	0·03	n.d.	0·02	0·02	sm. tr.
NiO	0·06	0·04	0·02	n.d.	none	0·01	n.d.
MnO	0·26	0·24	0·15	0·22	0·11	0·08	sm. tr.
SrO	none	0·04	0·08	n.d.	0·08	tr.	none
BaO	0·08	0·50	0·29	n.d.	0·17	0·04	sm. tr.
Li_2O	none	tr.	tr.	n.d.	tr.	tr.	n.d.
	100·10	99·82	99·89	99·86	99·83	100·32	99·90
Less O		0·08	0·04				
		99·74	99·85				

A. Biotite-peridotite, No. 575, Crocknafoyle (1934, p. 605). Analyst, L. S. Theobald.

B. Biotite-pyroxenite, No. 485, Seeconnell (1934, p. 608). Analyst, L. S. Theobald.

C. Shonkinitic monzonite, No. 299, Seeconnell (1934, p. 617). Analyst, H. F. Harwood.

D. Olivine-monzonite, No. 337, Slievenisky. New analysis by W. H. Herdsman.

E. Syenite (Plauenite), No. 383, Slievenisky. New analysis by L. S. Theobald.

F. Mobilized sediment, No. 602, Slievenisky (1934, p. 603, No. 1). Analyst, L. S. Theobald.

G. Sediment. Weighted average, 2 parts greywacke, No. 712 and 1 part shale, No. 713 (1934, p. 603, Nos. 3 and 4).

Note.—The exact localities of the analysed specimens are marked on the map, Fig. 1.

The mafic minerals, common hornblende and biotite, are of approximately the same grain size as the leucocratic constituents of the major part of the rock. They are poikiloblastic; isolated

TABLE II.

Norms.

	A.	B.	C.	D.	E.	F.
q	—	—	—	—	—	29·46
or	3·34	4·45	28·36	28·38	34·47	17·79
ab	2·62	—	20·96	25·53	37·47	20·96
an	6·39	9·73	11·95	13·26	12·23	6·67
lc	—	13·52	—	—	—	—
ne	—	2·84	2·27	—	·43	—
c	—	—	—	—	—	4·49
di CaSiO$_3$	23·08	15·66	9·28	5·95	·23	—
MgSiO$_3$	16·00	10·70	5·70	3·54	·10	—
FeSiO$_3$	5·15	3·70	3·04	2·10	·13	—
hy MgSiO$_3$	8·50	—	—	7·62	—	7·50
FeSiO$_3$	2·77	—	—	4·52	—	8·58
ol Mg$_2$SiO$_4$	16·80	18·20	7·70	1·24	3·85	—
Fe$_2$SiO$_4$	5·92	6·73	4·69	·82	3·77	—
mt	3·02	3·71	1·39	1·00	2·09	·70
il	1·37	4·26	2·13	3·16	2·13	1·67
ap	2·35	3·70	2·02	1·72	2·02	·34
cc	1·10	·50	—	—	—	—
water, etc.	1·72	1·79	1·26	·80	·84	2·06
	100·13	99·49	100·75	99·64	99·76	100·22

Modes (percentages by volume.)

	A.	B.	C.	D.	E.	F.
Olivine	22·4	—	—	3·0	—	—
Augite	63·3	27·4	21·9	20·4	tr.	—
Hornblende	4·7	21·2	—	—	5·3	—
Biotite	5·4	45·3	24·3	6·8	8·9	29
Quartz	—	—	tr	ca2·2	tr	47
Felspar	—	—	53·5	63·7	82·8	22
Cordierite	—	—	—	—	—	
Apatite	2·3	2·9	·9*	·6*	·6*	—
Iron ore	2·7	3·2	tr.	1·3	1·8	—
	100·8	100·0	100·6	98·0	99·4	98

A. Biotite-peridotite, No. 575. Modal augite includes a little hypersthene.

B. Biotite-pyroxenite, No. 485. Modal hornblende includes 1·8 per cent. actinolite.

C. Shonkinitic monzonite, No. 299. Modal augite includes a little hornblende.

D. Olivine-monzinite, No. 337. Modal olivine includes ·5 per cent. serpentine. The figure for quartz is calculated, as indicated in the text, and subtracted from the amount of felspar actually measured, i.e. 65·9.

E. Syenite, No. 383. The rock contains a little sphene.

F. Mobilized sediment, No. 602. Staining method used to distinguish felspar + cordierite from quartz.

* These figures refer only to the larger crystals of apatite. The fact that they are low compared with the corresponding normative figures is due to the impossibility of measuring the apatite which occurs as fine needles in the felspar.

sinuous portions, which enclose and wrap round anhedral felspar, being in optical continuity. In one section a crystal of hornblende, of somewhat larger size then usual, contains a central core of augite. The augite itself encloses blebs and channels of hornblende, which exhibit intricate boundaries and are optically continuous with the hornblende rim. On the other hand, the hornblende rim contains outlying ragged blebs of augite which, in turn, are optically continuous with the central core. The appearance between crossed nicols is one of extreme intricacy. Moreover, the hornblende has an exceedingly irregular margin, with protuberant growths extending into and wrapping round neighbouring felspar. Such an association of hornblende and augite is not uncommon in specimens of syenite from Slievenisky.

The leucocratic portion of the rock contains oligoclase-andesine and soda-potash felspar, with here and there a trace of quartz. For the most part the felspars form an almost equigranular intergrowth. The texture, however, is very variable, and there are patches with a considerably coarser grain. In these, large crystals of oligoclase-andesine, which exhibit a patchy twinning, are intergrown with one another in a highly intricate fashion. They sometimes exhibit zoning in which the zones are highly irregular in outline. Associated with this plagioclase, and frequently enclosed within it, there are small very irregular scraps of soda-potash felspar, riddled (as in the olivine-monzonite) with exceedingly fine vermicular quartz. Neighbouring scraps of alkali felspar, though isolated, are optically continuous.

The felsic constituents not uncommonly contain inclusions of opaque material which may be dust-like in its dimensions, or appear as small dots, hairs, or rods ; blebs of biotite are also present. Iron ore occurs as an accessory in small irregular masses. It is crystalloblastic and since it wraps round and sometimes completely encloses felspar, it seems likely that it was of late development. Sphene is present in small amount and is also crystalloblastic. Apatite needles, sometimes hair-like in their dimensions, are common in the felspars ; larger crystals of apatite, which are bluish in colour, are of rare occurrence.

IV. CRYSTALLOBLASTIC TEXTURES.

It will be convenient here to sum up the evidence relating to the occurrence and mode of origin of the crystalloblastic textures in rocks from this area. Such textures are characteristic not only of the olivine-monzonite and syenite just described, but also of all the rocks of Seeconnell type (1934, p. 613 et seq.).

The petrological significance of crystalloblastic texture lies in the evidence it provides that crystal growth took place in a solid or highly viscous medium. It is known to be developed (*a*) as a result of recrystallization induced by the action of a neighbouring intrusion, and (*b*) as a result of reconstitution dependent on pneumatolytic or hydrothermal introductions, as, for example, when tourmaline develops in tourmalinized grits and other rocks. Moreover, it is now known that replacements due to artificially induced metasomatism[1] sometimes give rise to similar textures.

If the textures in the Seeconnell examples resulted from contact alteration attributable to the intrusion of a younger magma, then their occurrence and distribution should be in some way related to the granodiorite. However, there is no such relationship. The augite-biotite-diorite, to which the Seeconnell types grade westwards, lies nearer to the main granodiorite, yet in it sieve textures are rare and crystalloblastic developments in general are considerably less common. Such would not be the case if the crystalloblastic development of the Seeconnell rocks were a consequence of contact metamorphism. Moreover, on the northern margin of the Complex (see 1934, Plate xxii) two isolated exposures of hybrid types occur. One of these, on Legananny Mountain, is of monzonite (Seeconnell type) whereas the other, on Rough Hill, is of augite-biotite-diorite (Slievegarron type). The monzonite exhibits conspicuous crystalloblastic textures, whilst in the augite-biotite-diorite, which must have been equally influenced by the granodiorite, such textures are much less characteristically developed, except away from the granodiorite and towards the sediments, where the latter are migmatized by the augite-biotite-diorite.

It can only be concluded that the crystalloblastic textures are definitely not referable to the action of the granodiorite. Since there is no other younger intrusion which could have caused contact metamorphism, I have adopted the alternative explanation that the textures result from recrystallization during reconstitution due to the effects on the invaded rocks of pyrometasomatic introductions from biotite-pyroxenite and biotite-peridotite magmas.

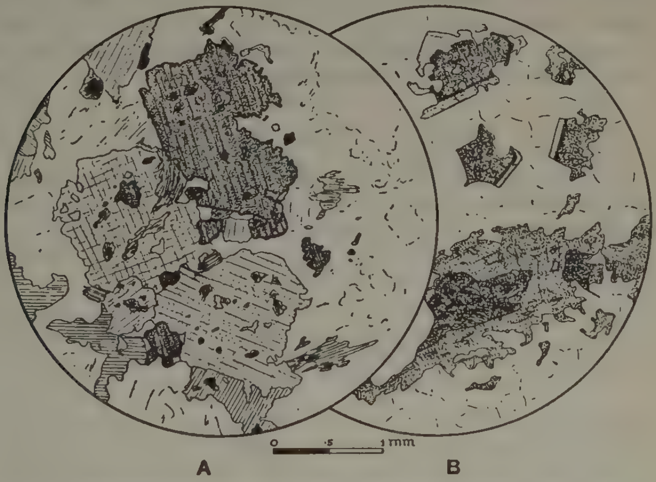
A similar problem relating to the genesis of poikilitic minerals was encountered by Gillson and Kania[2] in the course of an investigation of the mela-norite of the Cortlandt series. Poikilitic hornblende, with a rambling shape and sieved with felspar and pyroxene, is regarded as partly or entirely due to replacement. The form of the magnetite indicates that it, too, must have been formed partly or wholly by replacement during a late stage in the crystallization history of the rock. As indicated in the diagrams illustrating Gillson and Kania's paper, the minerals closely resemble the Seeconnell crystalloblasts in form, even as regards the detail of the development of "porcupine" biotite in the cleavages of the hornblende. Biotite of similar habit is not uncommon in the augites of the Seeconnell hybrids. For a detailed discussion of replacement and resultant textures, with an unusually full bibliography of the subject, reference should be made to Gilluly[1] on the replacement origin of albite-granite.

---

[1] C. Shouten, *Econ. Geol.*, **29**, 1934, 611–658.

[2] J. L. Gillson and J. E. A. Kania. *Econ. Geol.*, **25**, 1930, 511 et seq.

As a result of his examination of some of the Seeconnell monzonites, Professor Bailey has suggested that the ragged augites, which I regard as porphyro-poikiloblasts, are phenocrysts, representing some of the earliest products of crystallization, corroded by an alleged residual melt. Of one example he writes (Memo., p. 269), "the crenulate borders abruptly cross zoning marked by iron ore, and corrosion seems certain." It must, therefore, be pointed out that such an appearance is far from being inconsistent with a porphyroblastic development. In particular, I would refer to the development of tourmaline in a grit near Ivy Tor, Belstone, on the northern margin of the Dartmoor granite. In thin section the tourmaline commonly exhibits conspicuous zoning in tints of brown and blue. It is sieved with quartz inclusions and against the crenulate margins the quartz matrix frequently transgresses the outer zones. Some sections show a complete development of zones parallel to only one of the crystal faces. On the other faces the zones appear to be sharply truncated by the matrix (see Text-fig. 2).



TEXT-FIG. 2.—EXAMPLES OF CRYSTALLOBLASTIC TEXTURE.

A.—Olivine-monzonite (No. 337) from Slievenisky, showing augite, biotite, iron ore, and felsic constituents. The heavily shaded portions of augite are optically continuous with the main crystal, which is similarly shaded.

B.—Tourmaline in tourmalinized grit from the aureole of the Dartmoor granite; near Ivy Tor, Belstone, Devon.

If the sieve texture of the Seeconnell augites be attributed to corrosion, it becomes necessary to explain the absence of pyroxene or amphibole from the infillings of the sieves. If the sieves were due to solution, it seems impossible that the mafic material could in every case have been removed completely from such confined spaces. It is further to be noted that the tourmaline in tourmalinized grits exhibits isolated portions in optical continuity with a larger neighbour, exactly reproducing the structural details characteristic of the Seeconnell augites. Tourmaline is probably the best example that could be cited to illustrate the features which originate from the operation of pyrometasomatic processes. Independently of this comparison, however, it is inconceivable that small portions of augite, sometimes hair-like in delicacy, should be isolated from their parent crystal by corrosion due to a migrating residual melt, and yet remain in perfect optical continuity.

---

[1] J. Gilluly, *U.S.G.S. Prof. Paper* **175** C, 1933. See also C. S. Ross, *ibid.*, **179**, 1935.

V. The Two Monzonitic Series and their Relationships.

As already noted, field and petrographic evidence shows that biotite-pyroxenite, shonkinitic monzonite, and syenite form a gradational series. The chemical evidence now available further emphasizes this serial gradation (see analyses B, C, and E in Table I and the variation diagram, Text-fig. 3).

On Slievenisky, at the locality marked by No. 602 on the map, Text-fig. 1, the syenite in turn can be seen to grade to mobilized sediment. In describing the rocks of the Newry Complex the mobilized sediment was termed " fused sediment " (1934, p. 602). This name is unsuitable, however, since it introduces a thermal hypothesis into the description of a mechanical fact. This rock-type will in future, therefore, be designated *mobilized sediment.*

Although the mobilized sediment falls into subrang *Toscanose* (I.4.2.3.) in the C.I.P.W. classification, comparison with the numerous analyses that fall into the same division (e.g. the 381 analyses in Washington's Tables, 1917, pp. 201, et seq.) discloses the fact that this rock differs chemically from normal igneous rock-types in several important respects—notably by the abnormal combination in the mobilized sediment of low alkalies and high iron and magnesia, relative to silica. When the mobilized sediment is classified according to Johannsen's modal system (cf. mode under F in Table II), it is found to fall into the group of quartz-tonalites, 224P, in which quartz forms over 50 per cent of the leucocrates. Johannsen[1] observes that descriptions of only two rocks of this family are to be found in the literature. One is a paragneiss, described by von Eckermann[2] from Mansjö Mountain, Loos, Middle Sweden. The other, described by Eskola,[3] is a rock from the contact aureole of the Orijarvi area. Though Eskola believes this rock to be a metasomatized eruptive rock, he remarks that it has the composition of a sediment. The mobilized sediment is thus chemically, as well as mineralogically, more nearly of sedimentary than of igneous composition. Its chemical composition is plotted on the variation diagram, Text-fig. 3, and a weighted average of the local graywacke and shale (Table I, under G) is plotted for comparison. The latter, based on analyses of the two dominant types, is a sufficiently close approximation to the average sediment to demonstrate the fact that the mobilized sediment is chemically more closely comparable with the local sedimentary rocks than with the syenite to which it grades.

---

[1] A. Johannsen, *A Descriptive Petrography of the Igneous Rocks*, ii, 1932, 43.

[2] H. von Eckermann, *Geol. För. Förh., Stockholm*, **44**, 1922, 309.

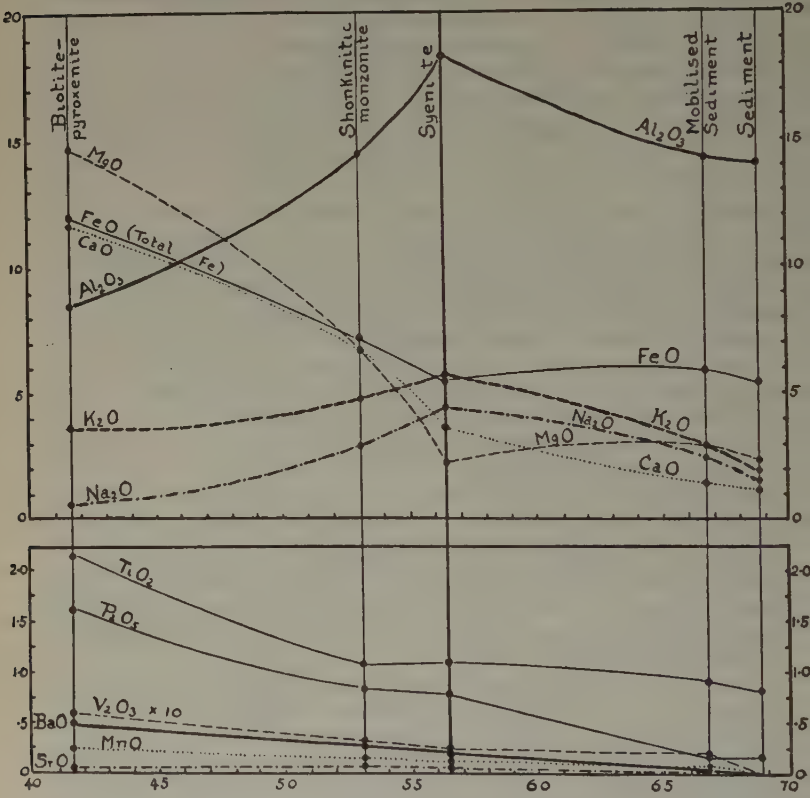
[3] P. Eskola, *Bull. Géol. Comm. Finlande*, **40**, 1914, 219.

On the basis of field relations and mineralogical and chemical composition I regard the mobilized sediment as resulting from the enrichment of the country rocks in alkalies, alumina and, to a less extent, in lime. The variation diagram, Text-fig. 3, shows that in these constituents the mobilized sediment is intermediate in composition between the country rocks and the syenite, and that it is more closely related to the former. The curves for iron and magnesia may appear to present an anomaly, since the mobilized sediment is richer in these constituents than either the syenite or the unaltered country rock. The rocks of the contact aureole, however, exhibit a marked increase in biotite, as compared with the normal sediment. Indeed, in certain lustrous black schistose rocks from the aureole, biotite may form as much as 50 per cent of the rock. This enrichment in biotite, which the mobilized sediment shares in common with the sediments of the aureole, is reflected by the convex form of the curves for iron and magnesia.

On the variation diagram, Text-fig. 3, the curves for the minor constituents are shown. They are of particular interest, since several of them fall smoothly from biotite-pyroxenite, through the hybrid types and the mobilized sediment, to unaltered sediment. This strongly suggests that these constituents were derived from the biotite-pyroxenite magma. The same conclusion applies to part of the TiO_2 and P_2O_5.

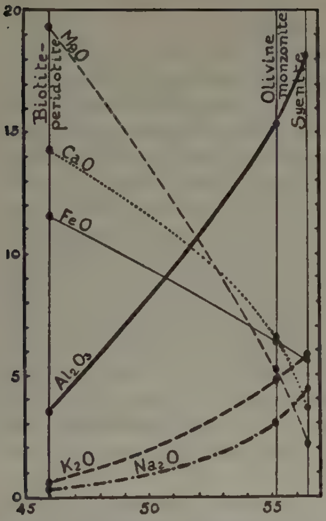
As already noted, the field distribution and mineralogy of certain monzonitic types, which in two localities contain olivine, indicate that they are related to biotite-peridotite rather than to biotite-pyroxenite. On the variation diagram, Text-fig. 4, olivine-monzonite is plotted together with biotite-peridotite and syenite. The serial relationship between these types is evident.

Comparison of the two variation diagrams, Text-figs. 3 and 4, indicates that there is a marked chemical relation between the biotite-pyroxenite series and the biotite-peridotite series. The main differences are expressed by the greater steepness of the various curves in the latter. For corresponding silica percentages, alkalies and alumina are lower, while magnesia and lime are higher, in the biotite-peridotite series. The mineralogical expression of this difference is that the biotite-peridotite and olivine-monzonite contain olivine and a relatively low percentage of biotite, whereas the biotite-pyroxenite and the shonkinitic monzonite contain no olivine, but have a high percentage of biotite. In other words, high alkalies (mainly potash) and alumina in the biotite-pyroxenite series led to the development of biotite rather than olivine. Normatively the members of both series are undersaturated. The chemical difference is, however, expressed by the fact that the biotite-pyroxenite series contains normative nephelite in addition to olivine, whereas in the biotite-peridotite and olivine-monzonite normative nephelite does not appear.

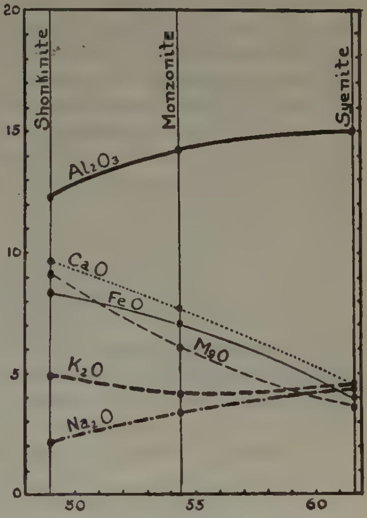


Text-fig. 3.—Newry Complex. Variation diagram of the series ranging from biotite-pyroxenite to country rock.

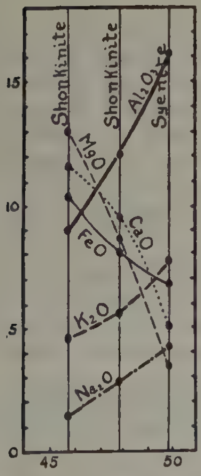
The relation between the two series is clearly displayed on the triangular diagram, Text-fig. 8. The line P—BP, directed towards the pole representing alumina plus alkalies, indicates the differentiation trend of the ultrabasic types. The variation-line of the biotite-peridotite series meets the variation-line of the biotite-pyroxenite series at syenite. Chemical gradation, therefore, corresponds in both



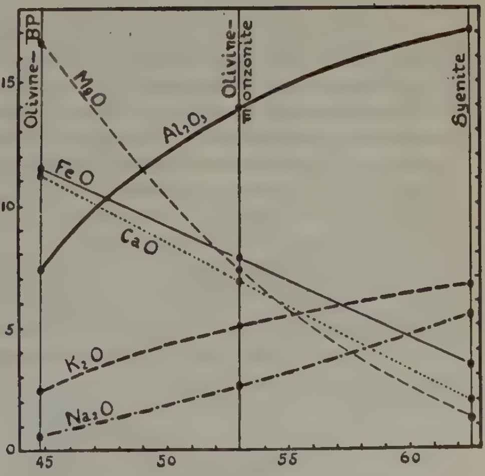
TEXT-FIG. 4.—Newry Complex. Variation diagram of the biotite-peridotite series.



TEXT-FIG. 5.—Yogo Peak, Montana.



TEXT-FIG. 6.—Shonkin Sag, Montana.



TEXT-FIG. 7.—Rossland area, B.C.

cases to field gradation. The diagram also emphasizes the greater richness of the biotite-pyroxenite series in alkalies and alumina, as compared with the biotite-peridotite series.

The mobilized sediment and the unaltered country rocks (graywacke and shale) are also plotted on the triangular diagram and, as in Text-fig. 3, the resemblance of the mobilized sediment to the sedimentary types is made evident. It is a point of great significance that the line drawn on Text-fig. 8 from average sediment through mobilized sediment continues through the calculated composition of the alkali-enriched sediment (1934, p. 629), towards the pole representing alumina plus alkalies. This indicates that the addition of a small amount (only 3 per cent.) of emanations rich in alkalies and alumina would be chemically adequate to convert the average sediment into mobilized sediment. The differentiation products of the ultrabasic magma can readily be ascribed to the effects of ascending emanations of essentially the same composition. It is therefore a reasonable inference that the emanations responsible for the alkali metasomatism of the sediments had their immediate source in the ultrabasic magma, that is, in the earliest known magma of the area.

It is further evident from the triangular diagram that the chemical composition of the various rock-types is consistent with the interpretation I have already given of their field and petrological characters (1934, p. 628). Chemically, the monzonitic and syenitic rocks are precisely what would be expected from syntexis of biotite-pyroxenite and biotite-peridotite magmas with alkali-enriched (syenitized) sediment.

VI. Comparison with Other Areas.

The Newry Complex provides the first recorded occurrence of the potassic series shonkinitic monzonite—syenite from rocks of Caledonian age in the British Isles. The suite is characterized by high alkalies, with considerably more potash than soda, and by high magnesia. In contrast with this, the Scottish Caledonian rock suites are, in general, marked by lower total alkalies, commonly with less potash than soda, and by higher lime than magnesia. Many of them are closely related to the appinites.

The most closely comparable suite—probably of Caledonian age—in the British Isles occurs in Sutherlandshire; its members have been described by Read [1] as the hybrids of Ach'uaine. They resemble the Newry rocks in their high potash, but differ in having higher lime and carbon dioxide, and lower magnesia and iron. Mineralogically, they differ from a typical shonkinitic series in their abundant hornblende. The hybrids of Ach'uaine represent transitional types between the shonkinite—syenite series and the appinite series.

---

[1] H. H. Read, *Mem. Geol. Surv. Scotland* (Strath Oykell and Lower Loch Shin), 1926, pp. 154–166.

In the Loch Ailsh mass, which is probably also referable to the Caledonian igneous cycle, the rocks parallel the shonkinite—syenite series of Newry, but are sodic in character.[1]

Biotite-pyroxenite is associated both with the hybrids of Ach'uaine and with the rocks of the Loch Ailsh mass. It thus forms a link with the biotite-pyroxenite series of Newry. It is a point of geochemical interest that the biotite-pyroxenite of Loch Ailsh, in accord with the sodic character of the associated rocks, is itself relatively rich in soda as compared with the biotite-pyroxenites of the other two areas.

The Seeconnell, Ach'uaine and Loch Ailsh rocks differ, in their high alkalies, from the other British Caledonian rock suites so far described. In this connection the alkali-lime index applied by Peacock [2] to the classification of igneous rock series provides a useful means of discrimination. Whereas all three of the suites mentioned above are alkali-calcic in character, the others so far described are calc-alkali, and, with the exception of that of Garabal Hill, contain more soda than potash.

TABLE III.

Alkali-Lime Indices.

Alkali Series.		*Alkali-calcic Series.*		*Calc-alkali Series.*	
Shonkin Sag, Montana	48·2	Loch Ailsh	51·3	Ben Nevis	56·6
		Rossland	51·9	Cairnsmore of Carsphairn	57·0
		Ach'uaine Hybrids	52·2	Loch Doon	57·4
		Newry (B. Pyr. Series)	52·2	Haddo House, Aberdeenshire	58·2
		Newry (B. Per. Series)	54·7	Garabal Hill	59·6
		Yogo Peak, Montana	54·75		

The indices for the typical shonkinitic series of Shonkin Sag,[3] Yogo Peak,[4] and Rossland,[5] are given for comparison with those of the Newry series. As regards individual rocks, the shonkinite of Yogo Peak and the olivine-monzonite of Rossland very nearly fit the variation diagram, Text-fig. 3, for the biotite-pyroxenite series of Newry. As regards the suites, the variation diagrams for Newry, Text-figs. 3 and 4, show marked resemblance to those for the Western American areas, Text-figs. 5, 6, and 7. The curves for the Rossland area, representing the biotite-pyroxenite and olivine-monzonite of Christina Lake, with the syenite of the Traill batholith as the end member, are most similar in their interrelations to those for Newry. The Shonkin Sag rocks fall within a small silica range and, as might therefore be expected, they are correspondingly rich in alkalies. The

---

[1] J. Phemister, *Mem. Geol. Surv. Scotland* (Strath Oykell and Lower Loch Shin), 1926, pp. 22–111.

[2] M. A. Peacock, *Journ. Geol.*, **39**, 1931, 54–67.

[3] L. V. Pirsson, *U.S.G.S. Bull.*, **237**, 1905.

[4] L. V. Pirsson, *U.S.G.S. 12th Ann. Rep.*, 1898–9, Part iii.

[5] R. A. Daly, *Geol. Surv. Canada Mem.* **38**, 1912, Part i. For the analysis of the biotite-pyroxenite see D. L. Reynolds, *Min. Pet. Mitt.*, **46**, 1935, p. 450, Analysis No. 5.

Yogo Peak series has higher lime relative to magnesia and is less rich in alkalies at the felsic end.

Of the three American shonkinitic series with which comparison is here made, only that of the Rossland area is known to have biotite-pyroxenite as its most basic member. It is, however, a point of interest that Pirsson in 1898, from a study of the rocks of Yogo Peak, actually anticipated the discovery of biotite-pyroxenite many years before the first example of this rock was described. Commenting on his variation diagram for the Yogo Peak series, he writes (op. cit., p. 575) :—

> "It shows that if differentiation had gone on as far beyond the shonkinite as the latter is from the monzonite there would have been formed, not a pyroxenite, but a missourite, and it shows the intimate relation between the latter and shonkinite. This relation is confirmed in fact, for the stock which furnishes the original missourite has shonkinitic phases.
>
> "We may thus deduce that in regions where monzonite occurs as a main stock type both shonkinite and missourite facies and dependencies are to be expected and should be carefully looked for.
>
> "It is also quite true that this deduced magma might express itself as a pyroxene-biotite rock (biotite instead of olivine and leucite), and especially if the magma crystallized under such conditions that water vapour and fluorine, necessary for the formation of biotite, could not readily escape.
>
> "The more basic type of shonkinite, described in the original paper and mentioned in this work under shonkinite, with its large and abundant poikilitic biotites, would thus in part be accounted for.
>
> "Such a rock, though of pyroxenic habit, is very different from the pyroxenites which represent the differentiation end products of the gabbro-peridotite group, as shown by its abundant potash, and is not to be confounded with them."

If it is clear from the data assembled in this paper that the Seeconnell hybrids constitute two monzonitic series ranging between potassic ultrabasic and syenitic types, then it becomes equally obvious that these hybrids cannot be referred to reaction between granitic magma and either gabbro, pyroxenite, or peridotite. Yet this suggestion has been offered and it is therefore desirable to refute it in detail.

(*a*) Reference to the variation diagrams (Text-figs. 3 and 4) makes it amply evident that the two monzonitic series are chemically, as well as mineralogically, essentially different from any known gabbro—granite or even gabbro—syenite suite. Potash is everywhere dominant over soda. Alumina varies sympathetically with the alkalies throughout the silica range. Magnesia lies above lime for all silica percentages below 52. The alkali-lime indices are 52·2 and 54·7 against an average of about 59 for gabbro—granite suites.

(*b*) There are no gabbros or granites associated with the Seeconnell rocks.

(*c*) In areas where gabbro and granite do react to produce hybrid types, the latter are not like those of Seeconnell.

(*d*) If granitic magma had reacted on pyroxenite to produce biotite-pyroxenite in the Newry Complex, the residual magma would have been greatly enriched in silica and impoverished in potash. No such abnormally siliceous sodic residuum can be traced, the most acid rock of the area being much less siliceous than normal granite.

(*e*) Similar objections apply to the case of peridotite.

VII. INTERPRETATIONS.

(*a*) *Mobilized Sediment.*

It has been thought possible by some petrologists that the zone of mobilized sediment resulted from the invasion and brecciation of sediment by igneous material, the latter not having been produced *in situ.* My own view, on the contrary, is that such igneous material as may be inferred from the structure of the zone is *igneous* only in the sense that its material temporarily attained mobility as a local result of ultra-metamorphsm stimulated by the introduction of highly energized emanations. Indeed, I can see no satisfactory alternative to the conclusion that the mobilized sediment consists of transfused (biotitized and felspathized) sediment, which contains inclusions of less altered sediment.

The transfusion process which endowed the material with the ability to move was, I believe, essentially one of metasomatism due to emanations, rich in alkalies and alumina, derived from the ultrabasic magma. To such a process Sederholm's term *anatexis* can well be applied, since Sederholm[1] attributed anatexis mainly to "the influence of emanations from the abyssal magma, whatever may have been its composition". The actual movement, or *palingenesis*, of the transfused sedimentary material is possibly to be attributed to either internal expansion, dependent on metasomatic additions (including energy), or to externally applied stresses.

This interpretation is based on (*a*) the mineralogical similarity of the mobilized sediment to the sediments of the contact aureole; (*b*) the gradation between mobilized sediment and contact-altered sediment; (*c*) the lack of chemical correlation between the mobilized sediment and igneous rocks (see p. 348); and (*d*) the evidence of the outer portion of a zone of migmatites on Rough Hill.

The latter zone, which margins the augite-biotite-diorite, retains a bedded appearance in the field. Close examination, however, reveals the fact that it consists of dark, closely packed, lens-like portions up to a few inches in length, embedded in a coarser material. The dark lenses, rich in biotite, maintain a linear and planar orientation parallel to the adjacent sedimentary bedding, and are obviously relics of altered sediments of the same type as the biotite-rich schist-like rocks of the aureole. The coarser material which surrounds the lenses is identical, both in hand specimen and thin section, with the mobilized sediment. It is mechanically inconceivable that the coarser material could represent an injection of magma, modified or otherwise. The conclusion seems inescapable that the coarser material has resulted from the action of metasomatic introductions (possibly both ionic and molecular) into the sediments.

---

[1] J. J. Sederholm, *Bull. Géol. Comm. Finlande*, **77**, 1926, 135.

After an examination in the field of the Rough Hill occurrences, Professor Bailey stated (1936, p. 267): "I accept the contention that much igneous material has marginally entered the contact zone of the sediments; also that it is probable that this penetration has occurred to some extent molecularly without disruption of bedding". In the light of this admission I can see no reason why the mobilized sediment should be regarded as an independent intrusive igneous type, since it is mineralogically and texturally identical with the coarser material of the Rough Hill outer zone. Nevertheless, referring to the mobilized sediment, Professor Bailey writes: "Where shown marginal breccia I usually felt that one could see modified igneous material invading modified sediment." That the mobilized sediment is igneous in habit, in that it contains inclusions of less altered sediment and exhibits signs of flow, I not only recognize, but actively maintain. But recognition that the material has at one stage been capable of internal mobility does not seem to me to compel the assumption that most of it was derived from an external source. I would here recall a pertinent remark of Quirke's with regard to an analogous occurrence. Writing of the Killarney area, Ontario, he says[1]: "we seem to find quartzites outside the borders of granitic invasions so completely altered into granitic material that they have partaken even of its physical activity, resulting in intrusive movements and actual invasion of other and less siliceous formations. *This is a critical point in any argument, that sedimentary rocks have been altered into igneous rocks.*" The italicized emphasis is my own, the object being to direct attention to a point which is persistently disregarded by many petrologists.

The mobilized sediment is not unique. Similar zones occur around many of the Scottish Caledonian intrusions. Moreover, it is instructive to compare them with an example figured by Sederholm[2] of a "Bedded leptite changed by palingenesis into an eruptive rock where some portions have flowed, while others have remained as fragments." Of the photograph illustrating this occurrence—which might well pass for one of the Newry mobilized sediment—Sederholm remarks:—

"The rock of the southern shore of Lingonsörn is a bedded leptite which retains in many places its character of a highly metamorphic schist showing an alternation of salic and femic beds. But the greater part of it has been changed, by a process surpassing metamorphism and even 'ultrametamorphism', into a rock which now behaves like an eruptive, but in which we still observe so much of the bedded structure of the leptite that it is obvious that at least a great part of the rock is simply a leptitic schist which has been 'ultrametasomatically', if such an expression is allowed, changed to such a degree as to reach the stage of refusion."

---

[1] T. T. Quirke, *Bull. Geol. Soc. Amer.*, **38**, 1927, 762.

[2] J. J. Sederholm, *Bull. Géol. Comm. Finlande*, **77**, 1926, 28.

Elsewhere, Sederholm [1] states that the opponents of the idea assert that anatexis "can be proven only if we are able to show gradations from unmelted to melted rocks in which the original chemical character has been retained". Though the latter assertion cannot be justified, Sederholm records a close approach to such an example in his description of a conglomerate, on the north-west shore of Viasholm in Pernå, which is composed of waterworn pebbles of basic rocks, mainly meta-andesites. Amongst these rocks there are some "which behave like eruptives, penetrating the neighbouring conglomerate, but are obviously only portions of the same rock which have undergone fusion" (loc. cit., p. 130). Moreover, a "part of the conglomerate has simply been 'refused' without any addition of granitic material" (p. 130). In this occurrence Sederholm finds that both mineralogically and texturally the palingenetic conglomerate is a cross between a metamorphic and an eruptive rock. From the closely similar chemical analyses of the conglomerate and the palingenetic conglomerate (op. cit., pp. 134 and 136), it appears that the process of anatexis involved, not addition of magma as such, but an introduction of alkalies, principally soda, into the conglomerate.

The Newry mobilized sediment is just such an example. It retains the chemical character of the local sediments with but small additions, the necessary additions amounting to no more than 3 per cent of the resulting rock.

Further reference may now be made to the high biotite content of both the mobilized sediment and the contact hornfels (p. 349). The biotite enrichment results from metasomatism and appears to be dependent (*a*) on introduction of alkalies, and possibly of alumina and iron, from the emanations, and (*b*) on introduction of magnesia as a result of a forward migration of magnesia from an interior zone of sediments already overcome by the transfusion process. Wegmann has recently noted such an origin for migrating magnesium in discussing the advance of frontal zones developing about growing regions of migmatization.[2]

As already noted Professor Bailey regards the mobilized sediment as contaminated igneous material. Since the mobilized sediment grades in the field to syenite, the latter should, on this hypothesis, represent the invading igneous material. Reference to Text-fig. 3 shows that if such were the case then the mobilized sediment would be equivalent to four parts syenite and twenty parts sediment. That is, the syenite would have "assimilated" five times its own bulk of sediment. Even if it be assumed that the sediment had the extreme composition of the analysed graywacke (which possibility is the most favourable to the hypothesis) the mobilized sediment would be equivalent to eighteen parts syenite and twenty parts sediment, and the syenite would have "assimilated" one and a ninth times its own bulk of sediment. Thus, when considered quantitatively, even Professor Bailey's interpretation leads to a conception of "soak", rather than of assimilation. It has, moreover, the disadvantage that the proportion of introduced material (17 to 47 per cent) is too great for the application of the same hypothesis to cases where the sedimentary bedding is retained, as on Rough Hill. On my own interpretation this difficulty does not arise, since only 3 per cent of material need be introduced.

---

[1] J. J. Sederholm, *Bull Géol. Comm. Finlande*, **58**, 1923, 128.

[2] C. E. Wegmann, *Geol. Rundschau*, **26**, 1935, 327 and 328.

The petrogenetic significance of the mobilized sediment is that it provides evidence of an arrested stage in the generation of magma. The idea which needs to be stressed is that the mobility implies, above all, a concentrated influx and liberation of energy. The resultant behaviour of the energized material does not, in itself, imply that the whole, or even the greater part, of the material came from the same magmatic source as the energy. There is no warrant for the generalization that magma necessarily originates only in the hidden depths.

(b) *The Two Monzonitic Series.*

Criteria which must be taken into account in considering interpretations of the two monzonitic series include :—

(*a*) The parallel development of the respective rock sequences, as seen in the field (see Text-fig. 1), within the biotite-pyroxenite and biotite-peridotite series.

(*b*) The internal gradational characteristics of the two series (involving field relations and both mineralogical and chemical composition), and the extension of the gradation at the felsic end through mobilized sediment to hornfelsed sediment.

(*c*) The conspicuous crystalloblastic character of the two series.

(*d*) The similarity of the textures to those exhibited by migmatites, on Rough Hill, which have arisen through the soaking of augite-biotite-diorite "magma" into hornfelsed sediments (1934, p. 612).

Judged by these criteria, the two following interpretations (suggested by two of the petrologists who visited the area last year), to which more detailed references have already been made under appropriate headings, appear to be untenable :—

(1) Crystallization differentiation of basic magma, coupled with reactions due to migrating residual melt on early-formed crystals, and followed by contact metamorphism (see Bailey, 1936, p. 270). Crystallization differentiation is incompatible with the existence and distribution of the two monzonitic series, to say nothing of the

existence and distribution of the associated augite-biotite-diorites. It fails also to account for the variation of the minor constituents (see p. 349 and Text-fig. 3) and for the crystalloblastic textures. In turn, the latter cannot be explained either by corrosion due to migrating residual melt (p. 347) or by baking due to contact metamorphism (p. 346).

(2) Hybridization of peridotite, pyroxenite, and gabbro by later acid magma. The chemical and other objections to this hypothesis have been reviewed on p. 354.

The interpretation which I adopt is essentially one of cumulative pyrometasomatism of the invaded sedimentary rocks by the ultrabasic magmas, with accompanying introduction of energy, possibly in sufficient quantity to lead locally to the generation of magma (*migma* of Reinhard). The rising of successive gaseous phases from biotite-pyroxenite and biotite-peridotite magmas into the country rocks would readily account for the distribution of rock-types in the area of Seeconnell hybrids. The rising, at an early stage, of emanations rich in alkalies and alumina, both through and beyond the ultrabasic magma, would account both for (*a*) the differentiation of the ultrabasic magma with development of biotite-peridotite and biotite-pyroxenite in its upper parts, and (*b*) the felspathization (syenitization) of the country rocks (see Text-fig. 8). If this process were followed by the passage into the country rocks of magmatic material rich in cafemic constituents, in the one case from biotite-pyroxenite magma and in the other from biotite-peridotite magma, then two parallel monzonitic series with differences such as those actually observed, would necessarily result. To quote Fenner[1] :—

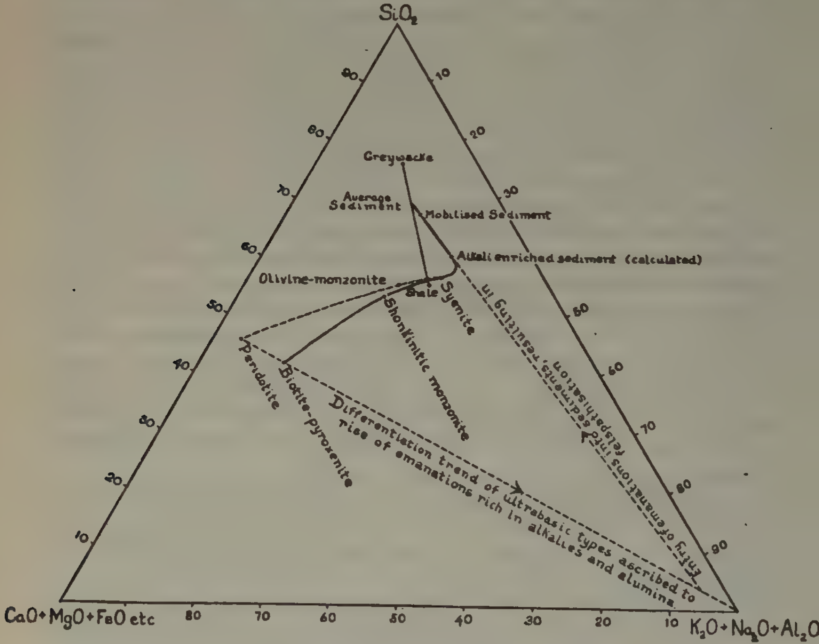
> "According to a simple principle of thermodynamics, in a system consisting of solid, liquid, and gas, if the solid and liquid are in equilibrium, also the liquid and gas, then the solid and gas must be in equilibrium. . . .
>
> "With reference to actual magmas and the minerals formed by gases escaping from them, these principles have important applications. It is apparent that modifications of the ideal system are required, but there should be a strong tendency to reproduce in the contact rocks the same minerals that are crystallizing in the magma."

In Text-fig. 8 the two successive, but possibly overlapping stages (*a*) introduction of alkalies and alumina, and (*b*) introduction of cafemic constituents, are diagrammatically illustrated for the biotite-pyroxenite series by the sharp bend in the line connecting *sediment—mobilized sediment—syenite—shonkinitic monzonite.* Two similar stages can also be recognized on the diagram for the biotite-peridotite series. It should perhaps be emphasized that no member of either series is regarded as a simple mixture of biotite-pyroxenite or biotite-peridotite and sediment. Indeed, comparison of the chemical analyses suggests that the cafemic constituents were themselves introduced differentially. The two successive stages referred to are comparable to those recognized by Quirke and Collins[1] in the Killarney area. There it is shown that the process of conversion of sediment to granite was one of felspathization, followed up and accompanied by the introduction of ferromagnesian-forming substances, in the later stages.

---

[1] C. N. Fenner, "Pneumatolytic Processes in the Formation of Minerals and Ores," in *Ore Deposits of the Western States*, Lindgren Volume, 1933, 80–81.

As already indicated (page 359), it is believed that the process of transfusion culminates in the development of magma. This belief is based (*a*) on the igneous habit of the mobilized sediment, which represents only an early and arrested stage in the process, and (*b*) on evidence of the development of syenite magma resulting from the process of felspathization of quartzite in Colonsay.[2] At the time when crystallization began, or was already in progress, any magma so formed might be homogeneous or inhomogeneous, according to the temperature and time factors. If, at the requisite temperatures, there was insufficient time for complete mixing of



TEXT-FIG. 8.—Triangular diagram to illustrate the chemical relationships of the two monzonitic series of the Newry Complex.

---

[1] T. T. Quirke and W. H. Collins, *Geol. Surv. Canada Mem.*, **160**, 1930, 54–5.
[2] D. L. Reynolds, *Min. Pet. Mitt.*, **46**, 1935, 460.

the mafic and felsic portions to be accomplished, an inhomogeneous magma of the nature of a temporary emulsion would result. Evidence of such inhibited mixing, an account of which is in preparation, has been found in Colonsay. The tendency to establish equilibrium might, in such cases, persist into the period of crystallization, and early-formed mafic minerals might then be attacked by the felspathic or quartzo-felspathic magma, which, having a lower range of crystallization temperatures, could originate even while mafic minerals were crystallizing, and, if formed, would certainly remain fluid for a longer time.

In conclusion, I gratefully acknowledge a grant from the Government Grant Committee of the Royal Society out of which the cost of chemical analyses has been defrayed. I wish also to place on record that the conclusions outlined in this paper have been reached in co-operation with Professor Arthur Holmes. We feel some confidence in maintaining them because they are closely interlinked with the results of other investigations on which we are engaged.

APPENDIX: REPLY TO PROFESSOR E. B. BAILEY.

After this paper had been submitted to the GEOLOGICAL MAGAZINE, Professor Bailey's *Memorandum*, which had previously been circulated, was published (GEOL. MAG., 1936, pp. 267–70). The more important points raised in the *Memorandum* had already been reviewed in the paper. By the courtesy of the Editors I am permitted to add the following systematic reply to Professor Bailey's remarks, in order to deal with those which find no place in the discussions of the preceding pages. The numbering of the paragraphs that follow correspond to those of the *Memorandum*. References to the original Newry paper (*Quart. Journ. Geol. Soc.*, 1934) are made by year and page; references to the present paper are made by page only.

1. For a discussion of the evidence and interpretation of the "contact zone" and "marginal breccia", to which I refer under the term *mobilized sediment*, see pp. 348 and 355 et seq.

Professor Bailey's reference to the Rough Hill area is to migmatites which contain hornblende porphyroblasts. I agree that the rocks in question are essentially igneous in composition, but I infer from their retention of bedding that they were developed from sediment, and therefore consider that they resulted from intimate soak.

2. (*a*) As pointed out on p. 356 et seq., examples are already known which prove that metasomatic introductions may so thoroughly mobilize the invaded material as to allow the latter to simulate the appearance of normal igneous intrusion. The fact that the party were not agreed as to whether the material in question was an "igneous vein" or a metasomatized portion of the graywacke (i.e. of the sedimentary raft), itself emphasizes that transitions from sedimentary to igneous rocks occur.

(*b*) What Professor Bailey regards as pseudomorphs after olivine are aggregates of small granules of diopsidic augite and rhombic pyroxene, associated with biotite, iron ore, and apatite (1934, p. 615). I know of no evidence that would suggest the possibility that these aggregates might be pseudomorphs after olivine. Professor Bailey was repeatedly asked if there was any such evidence; from the vague replies, and the absence of any reference to such evidence in the *Memorandum*, it appears that his interpretation is based on a purely personal impression. See under paragraph 6 for further remarks on alleged pseudomorphs after olivine.

3. None of the rocks in the area under discussion are gabbro-diorites. The rock to which Professor Bailey specifically refers is the analysed augite-biotite-diorite (1934, p. 611). As pointed out on p. 337, it is an undersaturated essexitic gabbro of petrological affinities very different from those of the gabbro-diorites. The other rocks belong to shonkinitic and monzonitic types, as already shown in the proceeding pages. Professor Bailey was referred last autumn to Tröger's *Kompendium*, 1935, p. 146, for a survey of gabbro-diorites. Nevertheless, nine months later he still repeats the original error.

I do not understand what Professor Bailey means by his statement that biotite-pyroxenite is "not fully represented in Argyll". It will, however, suffice to point out that the type is already known from Colonsay, Glen Orchy, Kentallen (recently found by Mr. R. M. Laurie), and just over the boundary beyond Loch Shiel; everywhere with associates similar to those of the Newry Complex, though generally less conspicuously potassic.

4. The felspathic types referred to occur only in the biotite-pyroxenite and augite-biotite-diorite, and so far as field observation is concerned there is no disagreement.

5. My interpretation of the augite-biotite-diorite was based on the evidence of intricate and nebulous veining of the biotite-pyroxenite by plagioclase (essentially). The pegmatite vein to which Professor Bailey refers towards the end of paragraph 5 has no bearing on this question. It is obviously of later introduction and as such received separate description in the Newry paper (1934, pp. 592 and 625).

Professor Bailey's positive statements *re* slowly crystallizing magmas relate to an unproven hypothesis and not to proven fact. It is obviously impossible to know—as Professor Bailey claims to—that the Newry exposures are "exactly analogous to those shown by many slowly crystallizing magmas" which have behaved in the hypothetical manner he imagines. His references to Mull and the veins in quartz-dolerites are, in fact, references to his own opinions and not to relevant evidence. This has already been clearly demonstrated by Professor Holmes (GEOL. MAG., 1936, p. 228), who shows that Professor Bailey's opinions are inconsistent with (*a*) mechanical fact; (*b*) the physico-chemical principles of crystallization differentiation established by the work of Bowen and his colleagues; and (*c*) field associations.

Such evidence as directly bears on the origin of the quartz-dolerite leucocratic veins is indeed in favour of what Professor Bailey states to be in his opinion impossible. Falconer (to whom Professor Bailey refers me) in describing such micropegmatite veins and interstitial portions in the Linlithgow quartz-dolerite sills notes (*a*) that "in places peculiar ragged portions of quartz occur in the midst of linear micropegmatite and simulate very closely corrosion effects" and (*b*) that "The amount of quartz increases, as a rule, towards the centres of the interstitial spaces, and angular fragments or irregular portions of the same mineral are frequently found embedded in the linear micropegmatite". In the gabbro sills of the north shore of Lake Huron, leucocratic patches, which are richer in felspar than the normal rock, have been shown by Collins to result from diffusion of various constituents from the gabbro-magma into xenoliths of quartzite (W. H. Collins, *Geol. Surv. Canada, Mem.* **143,** 1925, p. 80; and *Rep. XVI Int. Geol. Cong.*, Washington (1933), 1935). Recently Mountain (*Trans. Geol. Soc. South Africa*, **38,** 1936, pp. 93–112) has described the transformation of Table Mountain Sandstone into granophyre occurring as veins in an olivine-dolerite sill of Karroo age; the evidence is conclusive. Professor Holmes and I have found equally conclusive evidence of the transformation of quartzite into leucocratic veins occurring in "epidiorite" sills near Malin Head.

6. The question of the origin of the "ragged augites" is fully discussed on p. 347.

Professor Bailey claims to have "found that pseudomorphs after olivine (some may be after hypersthene) are common, though not interpreted as such". He regards as pseudomorphs after olivine not only the pyroxene granules mentioned under paragraph 2 (*b*) of this appendix, but also "aggregates of a pale actinolitic hornblende" and "aggregates of actinolite associated with iron-ore". I do not know why he should think that these actinolitic aggregates represent olivine; he produced no evidence. Presumably the argument is that since Becke found olivine inside pilite, therefore every aggregate of acicular amphibole, even though it is not observed to be associated with olivine or to have the form of olivine, must nevertheless be pseudomorphous after olivine. It may, however, be pointed out that actinolite aggregates similar to those in the Newry rocks occur in the Ducktown area as metasomatic replacements of quartz (C. S. Ross, *U.S.G.S., Prof. Paper*, **179,** Plate 10 C). The only evidence in the Newry area which relates to the origin of actinolite aggregates is that the latter are sometimes seen to be replacing diopside (1934, p. 615).

In the olivine-monzonite every stage of replacement of olivine by serpentine is represented from 100 per cent olivine to 100 per cent serpentine; the correlation between olivine and serpentine pseudomorphs is therefore complete. There is, however, no correlation whatsoever between olivine (or its form) and either the clusters of pyroxene granules or the actinolitic aggregates. Incidentally, it may be pointed out that if there were evidence that the minerals under discussion replace olivine, this would in no way vitiate my interpretation of the rocks. I cannot agree with Professor Bailey that there is any necessity to " assume " that olivine has crystallized from a melt. Both forsterite and fayalite are well known in contact zones and, so far as I know, nobody believes that forsterite-marble, for example, crystallized from a melt. It is necessary to judge each rock on its own merits. Relevant evidence relating to the Newry olivine-monzonite is discussed in the preceding pages.

7. For a detailed discussion of the points raised under paragraph 7 see the description of quartz vermicules in felspar, to which Professor Bailey refers as " abundant micropegmatite ", on p. 340. See also Plate V, and the analysis, norm, and mode of the olivine-monzonite listed under D in Tables I and II.

8. There is no evidence whatsoever in the area of the conversion of amphibole into granules of enstatite or of any other pyroxene.

For a description and discussion of cloudiness in felspars of the Newry rocks, see p. 341, where it is shown that the cloudiness is not referable to contact alteration.

9. Professor Bailey states, " I am of opinion that the basic rocks at the east end of the Newry complex are full of illustrations of differentiation by crystallization coupled with the necessary concomitant reactions." The facts with which this opinion is inconsistent are summarized on p. 358. Here, perhaps, it may be emphasized that the adverse comments made by Professor Bailey do not amount to scientific criticism since they are only expressions of his opinions, feelings, and expectations.

I do not need to be reminded of Dr. Bowen's work, for which I have a great admiration and to the stimulus of which I should like to pay tribute. I am, however, aware that many phenomena have been recorded which are incompatible with crystallization differentiation ; that there is a growing literature on the metasomatic origin of rocks of igneous composition ; and that we are still a long way from being able to formulate any general principles of igneous rock genesis.

EXPLANATION OF PLATE V.

Fig. 1.—Olivine-monzonite, No. 337, from Slievenisky, north-east corner of the Newry Complex. × 43. The mineral on the left of the field is olivine, fringed with a corona structure in which there is an inner zone of rhombic pyroxene and an outer zone of biotite. Crystals of apatite are associated with the corona. The right of the field shows soda-potash felspar riddled with vermicular quartz. The black patch at the top of the field is biotite and iron ore.

Fig. 2.—Part of Fig. 1 more highly magnified. × 210. The crystal to the upper left of the field is the apatite just above the centre of Fig. 1. The detail of the symplektite shows (*a*) the minute size of the quartz vermicules ; (*b*) the presence of acicular iron ore cutting through both quartz and felspar ; and (*c*) the crystalloblastic character of the corona, the biotite fibres of which (seen below the apatite) penetrate the symplektite.

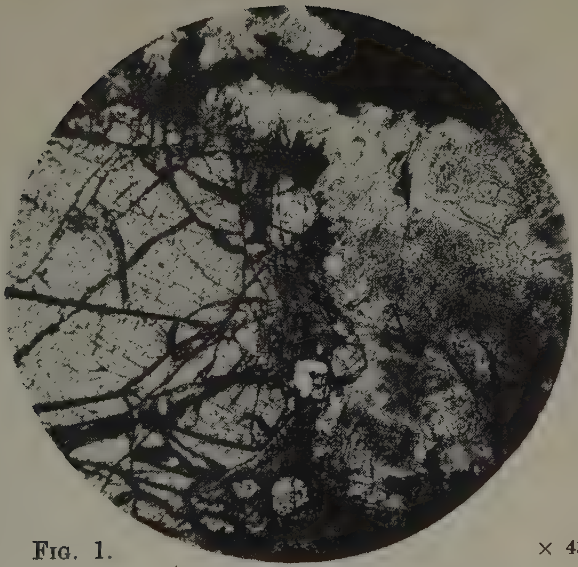


FIG. 1. × 43

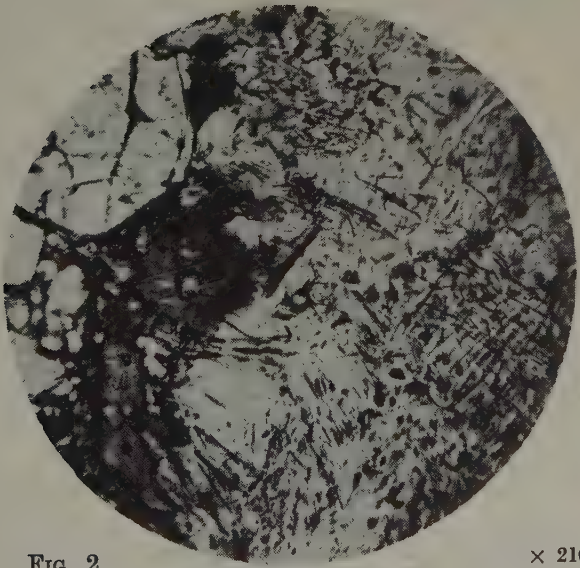


FIG. 2. × 210

G. W. O'Neill Photo.

QUARTZ-FELSPAR SYMPLEKTITE IN OLIVINE-MONZONITE

Notes on the Petrology of the Gadabursi Country, British Somaliland.

By John Parkinson.

(PLATE VI.)

Introduction.

DURING the course of several journeys from the port of Zeilah southwards across the Ban or Plain to Buramo on the Abyssinian frontier, collections were made of characteristic crystalline rock groups in the hope of elucidating to some degree the composition and early history of the district. Permission to publish these notes was kindly given by the Colonial Office.

Other work necessarily limited the time given to this study, and much ground had, unfortunately to be left untouched. Published information consists principally of Farquharson's summary,[1] published in 1924, and brief notes by Harker [2] in Macfadyen's work of 1933, so that in general the interrelationship of the wide variety of rock types found remains undescribed.

Among those of igneous origin, a widely distributed group of epidiorites and hornblende-schists (plagioclase-amphibolites) with consanguineous, later foliated granites is conspicuous, and forms an important part of the district north of Buramo. These have been termed the Buramo Schists,[3] a distinctive name being thought advisable because of their considerable extent and possible value as forming a datum to which to refer others in a very complicated country.

The district, often called the Gadabursi country from the name of one of the predominant tribes inhabiting it, forms an easterly offshoot of the Abyssinian plateau, and in its deep-cut valleys and on its rugged hills provides an abundance of exposures.

Evidences of early crush and shear are almost universally conspicuous, the vertical planes of foliation and movement not infrequently overlain by gently dipping but faulted Jurassic sediments.

The Buramo Schists.

The brief account of these rocks already published was based on field work and hand specimens only, but some thin sections subsequently cut allow their microscopic structure to be summarized.

The Dumuk Tug near Buramo provides an admirable and typical section. The series varies from massive gabbroid and dioritic rocks with associated, strongly foliated hornblende-schists, hornblende-biotite-schists, to fine-grained uniform pepper-and-salt gneisses, very acid intrusions and thin pegmatites. As usual, the basic element in the complex predominates, but locally the proportions are nearly equal, and lenticular and irregular banding on a large scale results, accompanied by definite brecciation by the acid gneiss, with later stages when sharp angular fragments pass into a composite gneiss, containing shreds and wisps of basic schist.[1] The brecciated rock, when least contaminated by the acid intrusion, is a close-grained, foliated brown-grey schist consisting of a mass of hornblende crystals, showing a strong blue element in the pleochroism, accompanied by magnetite, epidote, and biotite forming a mesh infilled by felspar and a little quartz, the former occasionally at least andesine, but often zoned and usually not twinned.

---

[1] R. A. Farquharson, *The Geology and Mineral Resources of British Somaliland*, 1924.

[2] W. A. Macfadyen, *Geology of British Somaliland*, App. i, p. 42, 1933.

[3] Geol. Mag., LXIX, 1932, 517–520. This contains a sketch-map, giving the positions of places mentioned in present paper. Also G. Stefanini, *Consiglio Naz. delle Ricerche*, "Saggio di una carta Geologica dell' Eritrea, della Somalia e dell' Etiopia," Florence, 1933, 1 : 2,000,000.

The rock recalls some of the Landewednack hornblende-schists and is doubtless of igneous origin.

As far as seen, pyroxene is rare, but diopside was found in a banded hornblende-schist occurring in prevailingly acid gneiss between Bid an Bid, N.N.E. of Buramo, and the descent to Dobo (Pl. VI, fig. 1). In this, light-coloured bands, containing diopside and much quartz, alternate with others containing predominant hornblende, water-clear, often untwinned and zoned andesine and oligoclase-andesine. Sphene is a common accessory mineral, also zircon, apatite, and epidote. The pleochroism of the hornblende is (α) greenish-yellow, (β) and (γ) dark bluish-green. Slight variations occur but the mineral appears to be near to pargasite.[2] The origin of the pyroxene is doubtless the same as in the Lizard and Kolar schists.

The acid part of the complex is represented by a salmon-pink, uniform, compact gneiss forming a conspicuous hill near to and west of Buramo. The quartz occurs in thin lenticles, microcline is plentiful together with oligoclase and oligoclase-andesine. A similar rock from near the descent to Dobo on the Bid an Bid track is a strongly foliated white gneiss in which the quartz lenses are ½ mm. thick by 7 to 8 mm. long. A high proportion of quartz is common, as in a vein 2 feet wide intrusive into the hornblende-schists at Dumuk, where the dominant constituent forms groups of large grains and lenticles or is disseminated through the rock. In this slide microcline is absent. A few flakes and crystals of biotite and epidote produce a speckled appearance. The untwinned felspar is apparently oligoclase.

The occurrence of subordinate biotite or hornblende, or both, products in part of absorption, causes a change of facies from place to place. Thus, 1 mile south of Buramo, near the motor road, the acid gneiss varies from fine-grained micaceous types to others containing occasional hornblende. Abundant films of white mica are found, e.g. west of Buramo, in a distinctly slabby rock, forming a vein in the schists, the quartz lying in lenticular streaks as before. A few very small crystals of a colourless garnet and a little colourless epidote are accessory constituents.

---

[1] See Harker in Macfadyen, 1933, *op. cit.*, p. 42, for a biotite-gneiss of hybrid origin occurring at Gumbur Gududan, some 50 miles E.N.E. of Sheikh.

[2] Cf. the hornblende-schists of the Suk Hills, *Quart. Journ. Geol. Soc.*, lxxxii, 1926, 586, and *ibid.*, lxxxiii, 1927, 790.

Farquharson records garnets (*op. cit.*, p. 39) in granite-pegmatites and hornblende-gneiss. These unfortunately were not seen *in situ* by me, although specimens rich in garnet were found in tug[1] beds. Pannings from gravels derived principally from the Buramo Schists produced very heavy concentrates, almost entirely of iron oxides but occasionally containing garnet.

Two specimens collected within 50 yards of each other, immediately to the west of the Buramo Rest House, illustrate the rapid change from slabby fine-grained hornblende-schists to massive, unfoliated rocks of gabbro type. The latter still show indications of ophitic texture, the andesine-labradorite is water-clear or slightly dusty, and the pale green hornblende, forming crystals measuring occasionally 10 mm. across, retains traces of diallage schillerization. The absence of blue in the pleochroism distinguishes it from the hornblende characteristic of the neighbouring schists. Flakes of a colourless chlorite are developed locally. The associated schist is a typical rock of the Lizard type, of granulitic habit, containing quartz, translucent andesine, probably varying somewhat in composition, and, as seen, no epidote.

Summary.

While the structure of the strongly foliated hornblende-schists is, in the writer's opinion, to be ascribed largely to fluxion along zones of relatively easy movement during consolidation, yet the effects of later pressure operating along planes, where rocks of less resistant nature existed, are also very conspicuous. The directions of foliation and of the zones of crush are both nearly north and south in the neighbourhood of Buramo. Variation in composition and structure is very rapid; thus in a few yards a crushed rock, of ultra-basic composition, is reduced to a mass of closely-woven chlorite or serpentine flakes, although traces of the schiller structure of the original pyroxene can be seen in some crystals, whereas the neighbouring rock is quite uncrushed and contains at least half its bulk as felspar, a constituent not seen in the preceding.

It is concluded, (i) that successive differentiations of varying degrees of basicity consolidated under plutonic conditions not necessarily producing foliation, and (ii) that later injections took the form of hornblende-schists and amphibolites, hornblende forming instead of augite along the edges of such masses or throughout the body of an injection.

---

[1] A sandy drainage channel, dry except in rainy seasons.

The effect of pressure subsequent to consolidation has already been considered.

The Section of the Abassa Dadera Tug.

Another section was examined in the Abassa Dadera Tug between Halleh Malleh and Abassa "Old Town", a locality about 15 miles in a direct line south-west from Dobo. The acid gneiss not only cuts the hornblende-schists but also brecciates a fine-grained hornblende-mica-schist of friable texture and chocolate-brown colour, closely resembling a schist intercalated with the Porphyries at Damal concluded to be of sedimentary origin. In the Abassa Dadera Tug markedly foliated green hornblende and subordinate brown mica are set in a granoblastic aggregate of quartz and acid plagioclase.

Other slides from specimens collected close at hand show a mingling of the two constituent rocks; in one a yellowish-brown mica is conspicuous, associated with hornblende and subordinate epidote (birefringence, 0·0307) and a little quartz.

The untwinned felspar is probably oligoclase.

The hornblende, frequently full of inclusions, has a pleochroism, (α) pale grass-green, (β) pale yellowish-green, and (γ) rather blue-green.

Injection gneisses show an irregular banding and a larger proportion of quartz; orthoclase and an acid andesine represent the felspars. Epidote is found in considerable quantity, associated with the biotite.

The hornblende-schists and related rocks do not differ macroscopically from those around Buramo. They include crushed actinolite-schists and also show veining of a close-grained hornblende-mica-schist by a coarse hornblende-mica-gneiss, itself believed to be a hybrid, showing, as do other exposures, that the intrusions took place at various stages of hybridization and differentiation.

Another type remains to be mentioned. It is a massive, faintly-foliated rock, the colour due to minute flakes of secondary biotite in a matrix of roughly equidimensional grains of untwinned felspar forming an irregular mosaic, the whole crowded with minute inclusions of white mica, blebs of felspar, and occasionally quartz. For this reason the slide has a minutely speckled appearance between crossed nicols.

A little quartz occurs in strings and patches. The felspar is apparently andesine, An. 20 to 40. The rock shows no sign of crush and is probably an intrusive dyke which has been subjected to thermal metamorphism, recalling the similarly altered intrusion to be described from the Bur Ad.

A colourless epidote and feebly pleochroic chlorite are rare accessories.

That such rocks, to be temporarily at least assigned to the Buramo Schists, have a wide distribution in the Protectorate, is shown by a small collection made at the foot of the Sheikh Pass close to the road leading from the station of that name to Berbera.[1]

The first of these, a massive speckled rock, very slightly foliated, represents the non-schistose state. Hornblende, having the usual bluish-green pleochroism and an extinction angle of 22°–23°, is conspicuous and is not infrequently surrounded by a corona of brightly polarizing epidote ($\gamma - \alpha$, 0·032) with vermiculae of the adjacent felspar. The slide also contains a pale green actinolitic hornblende, with patchy polarization, characteristic of altered or contaminated rocks, and this together with the presence of quartz, an acid plagioclase and orthoclase, probably indicate hybridization. Sphene, magnetite, and apatite are accessory minerals.

The typical hornblende-schist condition is shown by a slabby fine-grained iron-grey rock with indications of narrow bands or laminae. The water-clear plagioclase is medium andesine, but there is also an untwinned felspar which may be orthoclase. The texture is essentially that of many Lizard schists.

A third specimen, equally finely grained, is more definitely banded; thin dark hornblende laminae, alternate with others, pale yellow-green in colour, consisting largely of a mass of interlocking grains of epidote, having a birefringence of about 0·032. Larger grains enclose small crystals of hornblende. The usual bluish-green tint is noticeable in the pleochroism. A quantity of minute granules or prisms of rutile occur. (Pl. VI, Fig. 2.)

A slide in the British Museum (Natural History) Coll. [1920, 520 (56)] from 17 miles south-west of Berbera (about 35 miles north-west of Lower Sheikh) shows close resemblances to the record of these Sheikh specimens. The locality is shown on Miss Raisin's sketch-map.[2]

THE PORPHYRIES AND ASSOCIATED ROCKS.

The Damal Section.

Note.—This section forms the right bank of the Damal Tug about 1 mile above the end of the track from Zeilah and some 62½ miles from that port in a S.S.W. direction. The rocks described are close to the water-holes.

A remarkably bedded appearance characterizes the rocks composing the section. They are preponderatingly acid and igneous, and are interbedded with subordinate para-schists. Macroscopically, the former (referred to as Porphyries) are iron-grey in colour, streaked with yellow, showing a marked fissility due principally to fluxion, studded with felspar crystals and specks of magnetite. On some specimens minute flakes of mica are very obvious. The rocks are generally greatly crushed and the strike varies, as seen, from east and west to east-south-east to west-north-west with a northerly dip of about 30°.[1]

---

[1] Cf. Farquharson, *op. cit.*, p. 9. A list of localities of his "hornblende-gneiss" is given. Also Harker in Macfadyen, *op. cit.*, app. i, p. 42. Sheikh is 140 miles due east of Buramo.

[2] Raisin, C. A., *Quart. Journ. Geol. Soc.*, lix, 1903, 294, and GEOL. MAG., 1888, p. 414.

Quartz veins and pegmatites, parallel to the foliation or crossing it as filaments, are common. These are considered partly to arise from lateral secretion during metamorphism.

Small egg-shaped aggregates 5–10 mm. long of pink felspar and quartz may be small pebbles picked up during flow, while in one case similar collections of quartz grains resemble amygdules.

The direction of pressure is at right angles to that which so strongly affected the Buramo Schists, and one is tempted to think of the former as the result of movement earlier than, but along the same direction as that later marked by the great Aden Fault. The zone of fracture (as the writer believes) delimiting the hill region from the Zeilah Ban must pass near to Damal.

Microstructure of the Porphyries.

Thin sections show abundant crystals of orthoclase, rarely microcline and a plagioclase near to oligoclase, often 2 mm. in length, idiomorphic or rounded by crush, in many slides recognizable only with difficulty in ordinary light, but occasionally outlined by the development of mica and epidote around their edges and terminated by aggregates of coarser crystallization. (Pl. VI, Fig. 3.)

The formation of small spots or blebs of felspar or quartz shows partial recrystallization, a process which, if continued, would produce a microcrystalline structure identical with that of the base.

Twinning is often patchy and irregular.

Idiomorphic crystals of magnetite—exceptionally ½ mm. across—are common, and in some slides granular aggregates of sphene contain similar cores.

The rock itself is a fine microcrystalline aggregate of quartz and felspar, the former predominating.

Prism-shaped flakes of mica, dark green to straw colour, and rarely exceeding 2 mm. in length, are generally present, though varying greatly in quantity, and are frequently associated with innumerable minute granules of almost colourless epidote and indefinable dust.

---

[1] For the system of faults in the adjoining territory of French Somaliland see the map and memoir by Maurice Dreyfuss, *Rev. Géogr. Physique et de Géol. Dynamique*, iv, fasc. 4, 1931. For the fault system of the eastern part of the area described now, see Wyllie and Smellie, *Mem. Geol. Dep. Hunterian Mus. Glasgow*, pl. i, opp. p. 180, and the Geological Map of the Protectorate by W. A. Macfadyen accompanying his *Geol. of British Somaliland*. The present writer believes a N.E.–S.W. fault occurs near the Anglo-French frontier. It is noteworthy that the crystalline rocks do not appear in French Somaliland until the northern part of that Colony is reached.

Such sections resemble a fine-grained mica-schist and recall the metamorphosed rhyolites figured by Harker.[1]

Phenocrysts of quartz were not seen in the specimens from the right bank of the water-course but are common in one from the opposite side, together with felspar. This contains very little mica and in degree of crystallization of the base and in general appearance closely resembles a " porphyroid " from the " Trilobate " Plantation at Charnwood ; rocks considered as pressure-modified dacites.

The Damal Porphyries doubtless vary considerably in composition and in some sections " feather " crystals of a partially idiomorphic hornblende have formed, oblique to the direction of flow and having a pleochroism : (α) dark grass green ; (β) very dark green, almost black ; and (γ) as (β) but with a bluish tinge. The maximum extinction angle observed was 40° and the mineral is compared with hastingsite, a conclusion with which Professor C. E. Tilley, who kindly examined the slide, concurs.

Very broken outcrops projecting seldom more than a few inches from the soil are found on the top of the ridge on the north or left bank of the tug and about 1 mile above the end of the motor track from Zeilah. One of these resembling a Charnwood " Porphyroid " has been mentioned. It is a flinty, close-textured, purplish-grey rock of rhyolitic affinities, having macroscopic phenocrysts of quartz and very finely microperthitic felspar. Much iron oxide dust, occasionally forming minute idiomorphic crystals, is scattered through the rock.

Somewhat different is a coarser, microporphyritic granite or gneiss, greatly crushed and in a thin section showing a jumbled mass of microphenocrysts set in a microcrystalline matrix containing predominant quartz, frequently aggregated into strings. A little secondary white mica has been formed, larger ragged flakes of a dark green mica are probably original, and crystals of idiomorphic magnetite occur here and there. The plagioclase is oligoclase-andesine, and orthoclase is also a constituent. The rock is possibly a dyke but the field relations could not be seen.

Sediments Associated with the Porphyries in the Damal Section.

Very subordinate para-schists are intercalated among the Porphyries on the right bank of the Damal tug. Sediments in a similar state of metamorphism occur also in the Bur Ad tug on the track south-west from Damal. They are placed together in the suggested classification pending further information. The first of these is a very slabby epidotic quartz-schist, showing a faint banding owing to slight differences in composition due no doubt to original deposition. Minute epidote granules ($\gamma - \alpha$, 0·032) and subordinate greenish-brown and white flakes of mica, the former about 15 mm. long, constitute almost half the rock, coalescing into bands or strings in a fine-grained granoblastic mosaic of quartz and felspar, the latter not easy to detect. The rock is slightly lighter in colour than, but of the same flaggy type as, an altered grit from the north bank.

---

[1] *Metamorphism*, 1932, p. 288, fig. 149.

The second is a very friable, slabby, chocolate-coloured mica-schist. A dense mass of yellowish-brown mica is associated with a dark bluish-green hornblende, showing a marked tendency to form elongated prisms and clusters of epidote granules commonly aggregated into opaque ill-defined streaks. Quartz and subordinate felspar (in part orthoclase) constitute the remainder of the rock, which has a dusty, confused appearance due to imperfect crystallization.

This rock is clearly closely akin to the mica-schist brecciated by the granitic magma at Ạbassa Dadera and to the friable brown mica-schists occasionally found as inclusions in the hornblende-schists of Buramo. The latter, unfortunately, are too friable to allow of a thin section being obtained.

From the north bank of the Damal tug was collected a fine-grained, faintly laminated grit, consisting of a granoblastic aggregate of quartz and some felspar, the texture changing rapidly, due to deposition. Films of a greenish-brown mica have formed and the rock contains porphyritic felspars, including microcline. In type it resembles examples from the Bur Ad and is comparable with others from Buk Gego, but it must be admitted that the finely microcrystalline structure and the presence of large felspars makes such specimens at times distinguishable only with great difficulty from the "Porphyroids" of igneous origin.

Distribution of the Porphyries.

In regard to the distribution of these rocks in the Protectorate, Farquharson records (*op. cit.*, p. 10) "large masses of extremely foliated quartz porphyries" . . . "in the country round Besare . . ." (i.e. 10 miles east by north of Buramo) and "between Hemal and Buk Gego", "Intrusive masses" of "reddish and dark purple quartz porphyry", which may be those of Damal. He also mentions "more or less felsitic quartz porphyries" and "dykes of epidiorite" intrusive into the Inda Ad Series (p. 11). These are presumably younger than the rocks here described, but Harker states that soda-rhyolites or keratophyres are found on the Del R., Durfahri area, about 55 miles east-north-east of Sheikh. These he places in the Archaean.[1] The rocks exposed at Damal and those found in the Bur Ad doubtless belong to the same phase in the history.

Summary.

Flow structure and consequent differences of texture made obvious by differences of colour point to an extrusive rather than to an intrusive origin for these rocks and the abundance of felspar phenocrysts justifies the name of "Porphyries".

---

[1] In Macfadyen, *op. cit.*, App. i, p. 43.

The degree of metamorphism the associated sediments have undergone is indicative of the changes these presumed lavas have suffered, and the quartz veins traversing them point to the possibility of later silicification.

THE BUR AD SCHISTS.

Highly altered sediments from the west bank of the tug cutting the Bur Ad about 9½ miles from Damal on the track to Daba Dilla and Dobo, are termed the Bur Ad Schists.[1]

The section examined is not far from the junction of the crystalline rocks and Jurassic limestones, and the former, as far as could be judged, form the surrounding hills.

Taking representative specimens we have :—

(1) Macroscopically a compact, rather heavy pale grey rock, very closely speckled with black flakes about 5 mm. long after the manner of a "fruchtschiefer". These are ragged porphyroblasts of pale yellow-green to dark greenish-brown mica contained in a matrix of cryptocrystalline to micro-crystalline quartz and felspar. Here and there this mosaic becomes conspicuously coarser and contains innumerable very minute prisms of an almost colourless hornblende and chlorite. There is no conspicuous orientation. The rock is a highly altered argillaceous grit or arkose.

(2) A second specimen shows the mica xenoblasts much more strongly developed and abundant and about 1 mm. in average length. They are very ragged and irregular in outline, full of minute colourless inclusions, apparently of epidote, continuous from crystal to crystal regardless of orientation and, like the general foliation, presumably due to original lamination. (Pl. VI, fig. 4.)

Wisps of white mica are an important accessory constituent and form streaks and cloudy aggregates. The quartz shows a marked tendency to lie in thin bands or strings and occasionally shows strain shadows. The rock is a thermally metamorphosed argillaceous sediment, produced without noteworthy stress.

Of the arenaceous types are fine-grained, fawn-colour grits, flinty in the hand-specimen, consisting of a mosaic of quartz and felspar, the constituents being quite indistinguishable to the naked eye (Hornfels).

The quartz shows slight indications of strain, the felspars comprise rounded grains of orthoclase, rare microperthite and plagioclase referable to oligoclase and an acid andesine. No foliation is noticeable and the grains are rather ill assorted. Small granules of epidote, minute needles of actinolite and mica, for the most part bordering the original grains, have been developed.

---

[1] With these may be included, at least temporarily, the quartz and graphitic gneisses recorded by Farquharson from the Ulahleh Tug (? Yubalen) (*op. cit.*, p. 10). Possibly the products of thermal metamorphism mentioned by Harker (Macfadyen, *op. cit.*, p. 43) from Gumbar Gududan, near the centre of the Protectorate, belong to this group.

A second specimen proved as a whole still more finely grained; the section is clouded with secondary products amongst which minute granules of colourless epidote, flakes of white and strongly absorbent yellowish-green mica, kaolin dust and opaque dust, presumably iron oxides, are distinguishable. A few porphyroblasts of magnetite, 75 mm. across, are conspicuous. There is no foliation. The rock is a hornfels.

A hundred yards or so from that part of the section where these schists outcrop, rhyolitic rocks occur. They are characterized by marked flow structure, recalling the Damal porphyries, and flinty texture.

Phenocrysts of oligoclase or albite 1 mm. across are common and show irregular twinning. The structure varies from cryptocrystalline to microcrystalline, with occasional coarser patches or streaks accompanied by epidote crystals or magnetite dust frequently gathered into crystals.

As at Damal the phenocrysts are often partially resolved into a mosaic of secondary grains or traversed by veins from the surrounding rock. These rhyolites are grouped with the Damal Porphyries, from which they only differ by the absence of mica flakes and fineness of grain.

Associated Metamorphosed Intrusives.

With the Para-schists already described is a heavy, dark, greenish-grey rock composed chiefly of prisms of hornblende, 1 to 2 mm. long, and oval aggregates of felspar, their orientation showing a rough foliation. As seen in a thin section, the hornblende crystals lie at all angles, with an indication here and there of radial structure, in an almost translucent matrix of fine-grained, confusedly crystalline felspar, probably albite or an acid oligoclase. Small granules of epidote, spangles of amphibole and opaque dust are scattered plentifully throughout the section, while with the hornblende is associated a little brown mica and much magnetite as granules or semi-idiomorphic crystals. Chlorite is secondary after the mica. The hornblende shows the usual blue tinge in the pleochroism. The oval patches are believed to be metamorphosed phenocrysts: they are differentiated from the surrounding matrix by the absence of hornblende. Irregular veins traversing the specimen have a similar composition and may represent the consanguineous veins so common in dolerites. (Pl. VI, fig. 5.)

In other sections it is seen that the development of the hornblende has gone much further, but the base of the rock is more finely crystalline. The pleochroism of the hornblende is: (α) pale yellowish-green, (β) grass-green, and (γ) blue-green. The maximum extinction is about 23°.

The crystals, occasionally 4 by 0·4 mm., contain many small inclusions, and, while prism and pinacoid faces are well developed, the terminations of prismatic sections are commonly very irregular and fibrous. There is a slight tendency to a radial arrangement.

The crystallization of the base is confused, translucent by ordinary light, with multitudes of granules of epidote and iron oxides. Between crossed nicols it is seen to be partly cryptocrystalline and partly microcrystalline with relatively large-sized grains and coarser ill-defined patches here and there. The magnetite, occasionally idioblastic, is scattered through base and hornblende porphyroblasts alike.

A third variant of these rocks is composed almost entirely of epidote; in colour the hand-specimen is a dark, rather olive-green, having elongated porphyroblastic hornblendes up to 4 mm. long, a few whitish grains here and there representing the felspars of the original intrusion. In thin sections the mosaic of grey-brown epidote forms nearly the whole of the slides, the grains average 1 mm. or less across, the birefringence is about 0·036, the secondary hornblende is full of inclusions and has a pleochroism varying from yellowish-green to bluish-green. Films of magnetite are not rare. The rock is an epidosite.

Buk Gego.—[Buk Gego, an open water-hole, elevation about 1,625 feet, on the track from Damal to Iswadli via Las Gel. It is approximately 4½ miles from Damal on a bearing of 76° mag.]

The rocks as a whole are pink to flesh-coloured para-gneisses, the constituents indefinable to the naked eye, texture rather granular and tending to slabbiness. One is a uniform normal quartzite of fine grain, the others are not easy to distinguish from igneous rocks.

They usually consist of a uniform granoblastic aggregate of quartz and microcline almost devoid of mica. Parts of slides are composed almost entirely of quartz, the crystals occasionally cracked and showing crush shadows and the rock then resembles a quartzite instead of, as in others, an aplitic gneiss. It is concluded that they are the result of the metamorphism of the debris of a fine-grained granite or granitic gneiss.

In one instance, a few crystals of hornblende, about 2 mm. long, having the usual bluish-green element in the pleochroism, indicate that the greater part of the rock is igneous. At the same time occasional quartz grains show marked crush shadows, and have very round outlines indicating the addition of clastic material. Microcline is abundant and an untwinned oligoclase also occurs. Temporarily at least, these rocks are placed with the Bur Ad Schists.

Gubka Hadow.—[This locality is passed in travelling from Dobo to Abassa Dadera via Halleh Malleh. Elevation about 4,250 feet.]

To the east of Gubka Hadow are found well-bedded mica-schists of uniform grain, bands containing but little biotite alternating with others, usually thinner and coarser, consisting almost entirely of that mineral.

The "dip" is rolling, but the strike in general north and south. Porphyritic gneisses, characterized by abundant muscovite, form ill-defined bands approximating to *lit-par-lit* injections.

The mica-schists occur again in force some 3 miles to the south-west and at the same distance west of Gubka Hadow. A very fine-grained slabby gneiss with films of white mica on the foliation surfaces proved in a thin section to be a felspathic quartzite, the grains averaging about 1 mm. across, occasionally aggregated into rather coarser lenticles, the whole permeated by films of white mica. (Pl. VI, fig. 6.) It closely resembles in appearance the altered grit from the left bank of the Damal tug. Crush has contributed to the structure and the whole area has been one of considerable movement, the contortions of the mica-schists being very obvious.

Associated with the muscovite-gneisses, about 1 mile east of Gubka Hadow, is a friable pepper-and-salt gneiss, in composition a granoblastic aggregate of quartz and felspar, microcline and untwinned oligoclase-andesine, and foliation being indicated principally by the flakes of strongly absorbent biotite.

The quartz shows faint crush shadows, the plagioclase is occasionally slightly zoned and tinged with secondary products. It is thought that this rock and the Bihendula gneisses now to be mentioned are the result of the incorporation of an argillaceous sediment by a granitic magma, in the former case the muscovite-gneiss mentioned.

Bihendula.—A few specimens were collected from the road section about 5 miles north-north-west of Bihendula *en route* to Berbera. They are fine-grained, rather friable, markedly foliated, brown-grey very micaceous gneisses, usually rather indistinctly banded. They contain both black and white mica. In a thin section large numbers of flakes of a gummy-brown mica are conspicuous together with a few of muscovite; quartz, and felspar (microcline, microperthite, and an acid plagioclase) occur in approximately equal proportions.

Conclusions.

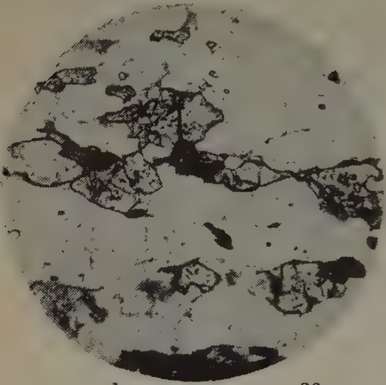
It is found that—

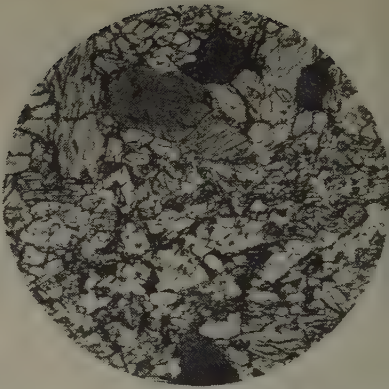
(*a*) A group of metamorphosed sediments, represented by fine-grained mica-schists and flaggy para-gneisses occurs in the Bur Ad, west of Gubka Hadow, Damal, and Buk Gego.

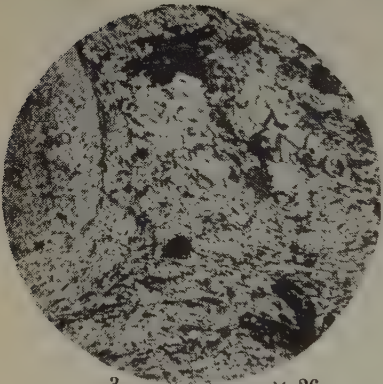
With them are associated thermally altered basic dykes, and,

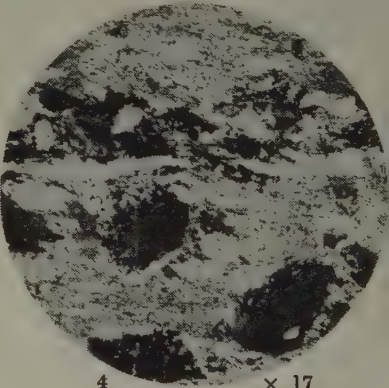
(*b*) A group of Porphyries, exposed typically on the right bank of the Damal Tug, 1 mile above the end of the motor track from Zeilah. They represent probably a group of lavas, varying in composition from rhyolites to dacites or even more basic rocks.

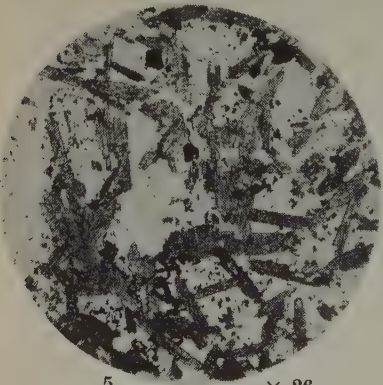
(*c*) The Buramo Schists. A complex group of coarse gabbroid

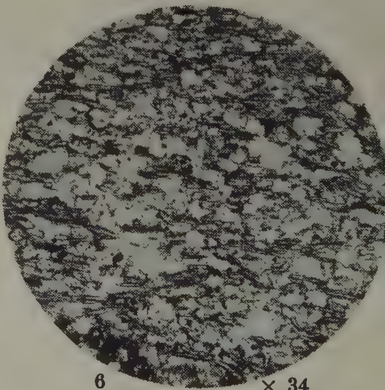

1 × 26


2 × 26


3 × 26


4 × 17


5 × 26


6 × 34

METAMORPHIC ROCKS FROM BRITISH SOMALILAND epidiorites, amphibolites, and hornblende-schists associated with an intrusive aplitic magma, possibly also intrusive into group (*a*).

As far as one may generalize from this imperfect investigation of part of the crystalline rocks of British Somaliland, sundry differences are observable when a comparison is attempted with the better known groups of Kenya Colony and Tanganyika Territory. The massive beds of marble that distinguish the Turoka Series in the north-west part of the Chemorongi (Suk) Hills on the west and extend on the east from the south of the Marsabit volcano beyond the Tanganyika frontier through Handeni almost to Portuguese territory are absent or poorly developed. Those and their associates belong to the "Kata-Zone" of Grubenmann, whereas the schists of Somaliland fall most readily into the less metamorphosed "Meso-Zone". I would accordingly place the rocks described in these notes in the Upper Group of the Archaean, or "Upper Basement Complex", as recently defined by E. O. Teale,[1] as distinct from his Lower or "Gneiss-Schist Complex", where the Turoka Series of Para-schists and associated Turkwal ortho-gneisses seem properly to belong. These Somaliland rocks would accordingly be of approximately the age of the banded ironstones, the spherulitic rhyolites, quartzites, and epidiorites of Stockley's "Musoma Series", characteristic of the south and south-east sides of Lake Victoria[2] in Tanganyika Territory. This is not the late Professor Gregory's view of the age of the specimens collected by Wyllie and Smellie, which he compared to the Lewisian and Bengal Gneisses and to the Swazi Series.[3] No doubt rocks belonging to the lower Archaean group do occur in British Somaliland but they were not definitely met with by me. Harker[4] comments on the apparent absence of the higher grades of metamorphism in the rocks he examined.

Finally I would express sincere thanks to the officers of the Mineral Department of the British Museum of Natural History for their kindness in having thin sections of the rocks cut and for facilities for study. Also my indebtedness to Professor C. E. Tilley and the late Dr. H. H. Thomas for examining certain slides, and to the latter for the photomicrographs which illustrate this paper.

EXPLANATION OF PLATE VI.

FIG.

1.—Pyroxene-hornblende-schist. Bid an Bid, N.N.E. of Buramo. Quartz-bearing bands containing a colourless pyroxene alternate with others in which hornblende is predominate.

2.—Banded hornblende-schist. Bottom of the Sheikh Pass, *en route* to Berbera. The banding is much clearer in the hand-specimen.

---

[1] *Tanganyika Terr. Geol. Sur. Dept. Bull.*, No. 6, 1933, p. 3.

[2] *Ibid.*, No. 7, 1935, p. 9.

[3] Gregory, "Coll. of Fossils and Rocks from Somaliland," *Monog. Geol. Dept. Hunterian Mus. Glasgow*, No. 2, 1925, p. 3.

[4] Harker, in Macfadyen, *op. cit.*, p. 42.

Fig.

3.—Porphyry of the Damal Tug section, right bank. The edge of a porphyritic felspar is seen on the left side.

4.—Metamorphosed argillaceous sediment. Garben-schiefer. Bur Ad. Xenoblasts of brown mica and cloudy aggregates of white mica films in a fine mosaic of quartz and felspar. A highly siliceous lamina crosses the field just above the centre.

5.—Metamorphosed dyke. Bur Ad. Part of a phenocryst lies on the left side of the field.

6.—Altered grit. Three miles west of Gubka Hadow. The remnants of a large felspar are seen on the lower edge of the field.

REVIEWS.

ZUR GEOLOGIE DER SÜDSCHWEDISCHEN BASALTE. By ROLF NORIN. *Meddl. Lunds Geol. Min. Institution*, No. 57. pp. 1–174. Lund, 1934.

THE basaltic rocks of Scania, about fifty occurrences of which are known, break through the Archaean gneisses of south-west Sweden and occupy a significant tectonic position on the outer edge of the Scandinavian Shield. In this and a preceding memoir (*Geol. För. Förhl. Stockholm*, 1933, 50, 101) the author describes at length the petrology of these basic rocks. As a group they show considerable petrographic variety ranging in composition from ultrabasic to basic olivine-basalts of alkaline character, and in texture from holocrystalline to vitrophyric. Nepheline-basalts and basanites occur among them but no leucite rocks are recorded. The detailed descriptions are supplemented by fifteen rock analyses and six analyses of titaniferous augites. Though incomplete (alkalis undetermined) the latter provide a welcome contribution to the chemistry of the pyroxenes of olivine-basalts. A concluding chapter provides data of a magnetic survey of some of the prominent necks. Magnetic disturbances are common over their outcrops but anomalies are restricted to their immediate vicinity and provide confirmation of their central type of eruption.

The presumed Tertiary age of these Scanian eruptions is supported by their chemical and petrographical unity with some of the Tertiary basalts of Central Europe (cf. H. Jung, *Chemie der Erde*, 1928, 3, 137).

C. E. T.

PLATINUM AND ALLIED METALS. 2nd edition. pp. 137. Imperial Institute, 1936. Price 3*s*.

IT may perhaps be somewhat of a surprise to many people to learn that at the present moment Canada is the largest producer of platinum metals, so far as can be ascertained, the figures given for Russia being obviously the merest guesswork. The enormous jump in the Canadian production in the last two or three years is due entirely to the development and standardization of methods of recovery from the nickel-copper ores of Sudbury, Ontario. The only other large producers are the Republic of Colombia and the Union of South Africa. The Abyssinian output of a few thousand ounces a year for the years 1926–1934 has now doubtless come to an end. There is also a steady annual output of five or six thousand ounces of osmiridium from the Rand gold mines. Rhodesia does not figure as a producer in the returns given in this Report, although the Great Dyke is known to carry ore similar to that of the Bushveld.

The volume under review, in which no author's name is given, follows the usual plan, and attains the usual high standard of the publications of the Imperial Institute. All the geological information has evidently been carefully collated with the now very extensive literature, as shown by the bibliography of 38 pages: a most useful feature. Even the discovery of a grain or two of platinum in the Lizard district, which was due to a casual suggestion by the present reviewer, is duly listed. In the interests of pure science it is to be hoped that there will be no return to the fantastic prices that ruled the platinum market some ten or twelve years ago: even now it is expensive enough to be a great handicap to workers in physical and chemical research.

R. H. R.

THE LOOS-HAMRA REGION. By H. VON ECKERMANN. *Geol. För. Förhl. Stockholm*, 1936, 58. pp. 129–336, pls. i-cix, with map 1 : 100,000.

THIS monumental memoir on the Loos-Hamra region deals with the geology and petrology of the rocky highlands in the province of Hälsingland in northern Sweden. The region surveyed covers an area of 1,200 square miles and extends into the neighbouring district of Dalecarlia. The district falls outside the region of Caledonian orogeny and a long succession of the pre-Cambrian record is preserved within its borders. Upon the oldest Archaean there follows the record of as least three great sedimentary epochs in each of which volcanic rocks play an important part. A minimum of five great granitic epochs is distinguished, these intrusions being known in most cases to intersect the volcanic succession with which they are correlated.

The eastern and south-eastern area of the field is occupied by the oldest Archaean—leptites, migmatites, and old gneiss-granites (granites of Group I in Fennoscandian terminology). Among the leptites, of which clearly recognizable fragments are seen only in a few localities, primary sedimentary features are traceable in quartz-banded iron ore sediments, limestones, graphite-schists, and coarse para-gneisses. Of a number of these the author has already given an illuminating account in his description of the eulysitelimestone series of Mansjö Mountain (1922). A reinterpretation of the eulysites now regarded as iron ore sediments will be welcomed by all students of this interesting group of rocks.

The largest area of this old Archaean mass is, however, occupied by more or less homogeneous migmatites containing varying proportions of leptitic material, old gneiss-granite and granites referred to the second epoch—the *Mansjö granite* (Group II). The position of this later granite in the succession is somewhat puzzling. In the period elapsing between the granites of Group I and Group II (Mansjö) there is no evidence in the Loos district of any great sedimentary series. In one place (p. 170) the author appears to give prime place to the Mansjö granite as the originator of the migmatites and this in itself raises the question whether the Mansjö granite is not a later phase of the old gneiss-granite succession rather than an independent group. Though the author regards the Mansjö granite as a "palingenetic" type, a detailed investigation of the old terrain has not yet been carried out.

Next in the major succession follows the *Sub-Loos Series* believed to rest unconformably upon the eroded edge of the Leptite complex. Consisting of schists and quartzites it has been preserved from erosion below an upper group of volcanics of the *Loos Series*. Its base is occupied by a sparagmitic quartzite formed by secular weathering of the older granites, and is itself intruded by later granites. The Sub-Loos Series gives the impression of having originally constituted a large, shallow, synclinal fold formed by subsidence. The Loos Series was initiated by conglomerates formed after uplift and erosion of the older Sub-Loos rocks. These conglomerates are followed by the eruption of spilitic greenstones, agglomerates, and tuffs, the spilites of which appear to have been poured out above sea-level. Above these come porphyry lava flows and tuffs. This *Lower Loos Series* is cut by the *Risberg Granite* (Group III), which, unlike the Mansjö granite, does not produce migmatites with the intruded rocks.

The *Upper Loos Series*, which rest unconformably on the porphyries, are dominantly slates, quartzites, and greywackes, less metamorphosed than the Sub-Loos sediments. The Sub-Loos and Loos Series, which form extensive outcrops in the vicinity of Loos, form part of a large north-west synclinal fold, which at its northern end forms a basin compressed from the north during the intrusion of the later Rätan granite. The Risberg granite is believed to have been intruded before the deposition of the Upper Loos Series. If this be so the unconformity at the base of this series acquires a special significance.

The *Noppi Series* of quartz porphyries, tuffs, quartzites, and slates developed in the western area is separated from the Loos sediments by a basal conglomerate containing pebbles of the Loos quartzites. These are succeeded by the *Ratan granite* (Group IV), occupying a large area in the northern district. This granite is known to cut the Noppi quartz-porphyries and appears as pebbles in the inter-Jotnian conglomerates of the *Dala Series.* It therefore belongs to the Noppi cycle and is genetically related to the Noppi quartz-porphyry suite.

The Dala epoch was opened by the formation of the Jotnian basal conglomerate composed largely of pebbles of the Noppi Series. Above it come the great group of Dala porphyries which extend westward into the great Dalecarlia porphyry area. The volcanic succession opens with intermediate effusives followed by acid porphyries (Lower Dala Series) while the magmatic succession in the Upper Dala ranges from strongly basic to acid porphyries. These volcanic horizons are separated by inter-Jotnian sediments. The Jotnian sediments are but slightly disturbed and lie horizontally or with a slight dip (10°–15°) to the south-west—towards the central part of the Dalecarlian porphyry region.

Rapikivi-like granites occupy a considerable area around Loberg and Sandsjö; pebbles of the latter type occur in the inter-Jotnian conglomerates, and the author is of opinion that two series of Rapikivis related respectively to the Lower and Upper Dala porphyries are represented in the province, which includes an area west of the present survey. An intimate connection exists between the Rapikivis and the porphyries; gradations exist between them, and granite intrusions followed closely upon the extrusion of the flows. These features make evident that they both belong to one continuous epoch of eruptive activity.

The author has shown that the Jotnian dolerites occupy a much larger area than has hitherto been supposed and appear more than once in the chronological succession. Their exposed area in the mapped region is comparable with and may exceed that of the Rapakivi granites.

The detailed petrographic and chemical data presented give strong support to the thesis that the porphyries, Rapakivis, and dolerites are all constituent members of one magmatic province, and the structural position of the Rapakivis renders it probable that no great erosion would have been required to expose them. The author's conception of the geological and petrological relations of the constituent members of his Dala Series is a revolutionary one in Fennoscandian geology, in striking contrast to the orthodox view of a great unconformity separating the Rapakivi granites from the Jotnian with an implied erosion extending to several thousand metres.

In support of his contention he points significantly to the common associations of Rapakivis, Jotnian sandstones, and dolerites throughout Scandinavia—a fact which presents grave difficulties of interpretation on the older viewpoint but simply elucidated on the view deduced from the evidence of the region under examination.

The real sub-Jotnian unconformity is to be found not above but below the Dala Series at the base of the conglomerate overlying the Noppi Series. In a concluding section the relations of the succession in the Loos-Hamra region to that of Central Sweden are discussed. For this purpose much of the data are still to seek, and the author is ready to recognize the tenuous character of proposed correlations.

In this review lack of space forbids a discussion of the many interesting petrological problems raised by the author's petrographical studies. His account is enriched by one hundred and fourteen chemical analyses carried out on the more important rock types, and these have added material support to his conclusions in the field of petrogenesis.

The memoir is beautifully illustrated with a large number of photographs, a large coloured map, and numerous sections. With its publication the Loos-Hamra region is elevated to the status of a key area in the pre-Cambrian of Fennoscandia.

C. E. T.

CORRESPONDENCE.

THE COMPLEX QUESTION IN JAMAICA.

Sir,—Dr. Matley's criticism of my paper in the June number seems to call for a few lines in reply. I should have stated that the granodiorite junction certainly is a steeply thrust one in some places, and as I see it, the plutonic complex is a discordant bathylith taking on to some extent the character also of a bysmalith. Along the Wag Water near Lawrence Tavern it sends veins directly into the purple conglomerate, but at the junction with the Iron River lumps of coarse-grained granodiorite have been disengaged and mixed with crushed material. Hornblende schist or rock closely resembling it occurs among hornfels on the Rio Pedro and the hornfels nearby has been formed out of pebbly material, possibly Richmond beds, and the pebbles drawn out to form the streaks in the hornfels. This in the midst of an area of unsheared granodiorite I can only explain by melting.

We are not dealing here with old deep-seated granite bosses with extensive aureoles, but with some unfamiliar Andean or Antillean more superficial effects about which there seems to be plenty yet to learn.

The section below the Lazaretto, p. 261, is as nearly as possible as I sketched and described it ; there is no possibility of an unconformity here, the section is one and indivisible. I can only suggest that it is due to gases travelling ahead of an intrusion melting their way rapidly into the white limestone and then coming to a standstill. The eruption of Mount Pelée showed us something of what such gases can do.

I do not consider any exposure that I have seen in Jamaica to be a basal complex or fundamental floor ; the thick and uniform white limestone is the last formation one should imagine to have been deposited among the peaks and valleys of a submerged land mass; completely missing out in this area the yellow limestone and other underlying beds which elsewhere are present all over Jamaica. I have never seen pebbles of the granodiorite in the undoubted Blue Mountain conglomerate and in my opinion it is impossible definitely to identify the source of origin of any of the pebbles in that bed. Being, to put it euphemistically, an indifferent petrologist, and not caring very much for joint papers, I preferred to leave out the petrology of the rocks; but I am informed that they do not show any extraordinary features.

C. T. Trechmann.

Castle Eden,
Co. Durham.

RIFT VALLEY IMPRESSIONS.

Sir,—Dr. Shand's paper, published in the Geological Magazine for July, entitled "Rift Valley Impressions", is bound to stimulate the differences of opinion which exist as to the origin of those greatly discussed features, the African Troughs. The Professor is but one of many; he is not the only investigator to desert exaggeration and plot sections across the Rifts to true scale and thereby to discover how insignificant these mighty rents become, or to comfort himself, if so he did, with the reflection that any of the earth's great features would be equally reduced to truer though less spectacular proportions if similarly treated. This, by the way. The interest of the African Troughs lies in their length and disposition, not their depth.

Speaking for myself, the Eastern Valley is not particularly impressive when seen from the air between Kisumu and Nairobi, and I am aware how comparatively insignificant it may appear when entered, say, from Rumuruti on a journey to Nakuru.

Lake Tanganyika, as seen between Kigoma and Kipili, is not at all diagrammatic when judged by the usual Rift standards. On the other hand, the outlook over the Rukwa Trough from the western edge near Sumbawanga is as astonishing as the view over the sunk-land of the Coastal Belt of British Somaliland seen from the edge of the escarpment east of Sheikh, part of course, of the same great system of faults. "Astonishing" is, on the whole, too weak a word. Even so, whether in Tanganyika Territory or in Somaliland the effects of erosion are sufficiently conspicuous. The structure of the Magadi section of the Eastern Rift, the succession of step-faults on the eastern side, the great Nguruman scarp on the west, seen not necessarily from the railway, but from an advantageous point near Turoka, is very impressive at dawn or dusk. The same is true of the northern end of Lake Natron. Many of the faults are relatively new. The fact that this "freshness" of the scarps is a function of varying age must be clear to anyone who has wandered in and out of the Rifts. Professor Shand's remark (*Proc. Geol. Soc.*, No. 1313, 4th June, 1936) that, "rift faulting was the consequence, not the cause of the regional volcanism" is in my opinion certainly true in the case of the Magadi section. The ten months or so I spent in the district were scarcely required to convince me of it: very little imagination is needed almost to see the blocks of lava sagging, like tombstones covering unconsidered graves as support was withdrawn. One cannot escape the conviction that the extravasation of the surrounding lavas was a cause, if only a subsidiary one, of the sinking. The case, however, appears different when other places are considered, such as Lake Tanganyika, where there are no lavas, although the bottom of the trough is very deep, 1,664 feet below sea-level.

When the enormous length of the Rifts is taken into account, together with the associated faults, surely no doubt can exist that some cause has been operative more fundamental in importance than local vulcanism, in other words, the manifestations of igneous activity are results and not causes, though minor local exceptions occur. I have believed for long in the ancient fault system upon which Professor Shand would seem to rely, but its existence merely pushes the answer to the perplexing "Why?" back into the obscurity of time.

Without professing to understand the origin of the present system of faults, the following facts for many years appeared to me to have a bearing on this subject.

(1) The existence of Lake Victoria in the centre of an almond-shaped horst outlined by the Central and Eastern Troughs, and associated faults.

(2) The concentration of great granite masses in the south and central portions of the horst, and

(3) The dominant and remarkable east and west trend of the foliation of the granite and rocks of the Upper Basement Complex south of the Lake and the general parallelism of the foliation elsewhere to the sides of the Victorian horst.

The size of the granite bathylith "G 3" is enormous and when allowance is made for reduction by erosion, its influence, first as a plastic and then a resistant body, on the history of Central Africa must have been very great. Contraction and especially partial relapse into the reservoir during cooling of a mass so gigantic would set up stresses and thereby produce lines of weakness around or in the vicinity of its edge, conceptions which later gave birth to that ancient system of faults which undoubtedly exists, though now so largely covered by later beds, or eroded out of recognition. And if a contributory cause is (and no doubt it is) necessary, why not the higher rate of rotation of the Earth in those far-off days?

John Parkinson.

The Athenæum,
Pall Mall, S.W. 1.
9th July, 1936.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIII.

No. IX.—SEPTEMBER, 1936.

ORIGINAL ARTICLES.

New Scottish Carboniferous Crinoids.

By JAMES WRIGHT.

(PLATES VII–X.)

CONTENTS.

I. INTRODUCTION.

II. DESCRIPTION OF SPECIES.
- (1) *Woodocrinus liddesdalensis* sp. nov.
- (2) „ *whytei* sp. nov.
- (3) „ *gravis* sp. nov.
- (4) „ cf. *expansus* de Kon.
- (5) *Pachylocrinus tielensis* sp. nov.
- (6) „ *dunlopi* sp. nov.
- (7) *Tribrachiocrinus caledonicus* sp. nov.
- (8) *Ulocrinus doliolus* sp. nov.
- (9) *Mespilocrinus* cf. *konincki* Hall.
- (10) „ *depressus* sp. nov.

III. LIST OF LITERATURE.

IV. EXPLANATION OF PLATES.

I. INTRODUCTION.

IT was indicated in a previous paper (GEOL. MAG., LXXII, 1935, p. 208) that the Scottish Lower Carboniferous crinoid fauna contains a number of species which have never been adequately described. In the present communication, ten of these are discussed, the remainder, another ten or eleven species, will be dealt with later. All the specimens except four were collected by myself many years ago, but it was only recently that the requisite leisure was found to develop and clean them thoroughly.

For the loan of specimens of *Woodocrinus* for comparison and study I have to thank Dr. W. E. Collinge, Keeper of the Yorkshire Museum, York; Professor A. W. Gibb, of the University of Aberdeen; Dr. A. C. Stephen, Keeper of the Natural History Department, Royal Scottish Museum, Edinburgh, and Dr. R. G.

Absalom, of the Kelvingrove Museum, Glasgow. I have also to thank Mr. D. Balsillie, Keeper of the Geological Department, Royal Scottish Museum, for the loan of a specimen of *Mespilocrinus* belonging to the Neilson Collection in that institution.

II. DESCRIPTION OF SPECIES.

DICYCLICA ADUNATA Bather,

DENDROCRINOIDEA Bather,

POTERIOCRINIDAE Roemer (emend. Wachsmuth and Springer),

POTERIOCRININAE Springer,

WOODOCRINUS de Koninck.

The genus *Woodocrinus* as described by de Koninck comprises the following species: *W. macrodactylus*, *W. expansus*, *W. goniodactylus*, and *W. dichodactylus* (1854, 1857). All are from the Yoredale Beds in Swaledale, near Richmond, in Yorkshire. The best known of these species is undoubtedly the first named, *W. macrodactylus*. It seems to have been found in large numbers and specimens may now be seen in many private and public collections. Probably the largest and most representative series is that of the Yorkshire Museum at York, which also contains the original specimens used by de Koninck in his descriptions of the different species. Figures of *W. macrodactylus* have also been copied or reproduced in various publications on geology and palaeontology and being fairly representative of the great bulk of the specimens, the general form of this species, which is the type of the genus, is well known to students. Its chief characters may be tabulated thus: crown consisting of a somewhat low turbinate cup surmounted by stout and for the most part regularly branching arms, of which there are generally four to the ray, composed of extremely short brachials with parallel sutures; a column of thick and thinner alternating ossicles which, in specimens where it is preserved to any length, seems to taper away to a point at the distal end. The number of primibrachs is one, secundibrachs commonly vary from four to eight, only occasionally exceeding this, and tertibrachs range from forty-five to seventy, the average length of a complete crown being about 75 mm. The general aspect of the arms is heavy, rounded, and somewhat short, and in fact more than one writer has not inaptly described them as worm-like or vermiform.

W. expansus is not so well known and appears to be represented by little more than two specimens in the York Museum. This species has more complicated arm branching and was further described and illustrated by G. Roberts in 1865. There is also a specimen in the Natural History Department of the Royal Scottish Museum which probably belongs to this species.

Of *W. goniodactylus* I have previously noted that it more properly comes under *Hydreionocrinus* and is closely related to *H. woodianus* de Kon. (1925, p. 281). The arms are biserial and branch in a similar manner to *H. woodianus*, in fact their only difference from this species seems to be that they are angular and not rounded in section. Recently, through the kindness of Dr. Collinge, Keeper of the York Museum, I have again seen the type specimen of *W. goniodactylus* and this opinion is confirmed. The species may therefore be left out of *Woodocrinus* at present.

W. dichodactylus is stated by de Koninck to have a total of fifty arms, but I have not so far seen the specimen to which this description might apply. I have, however, examined a small specimen with this name on the label, but it is probably erroneously marked since the specimen has regularly branching arms with only four to each ray, more after the character of *W. macrodactylus*, though with relatively narrower and higher brachials.

In 1910 I first noted the occurrence of the genus at Invertiel, and later (1914, 1917–1918) recorded the discovery of more specimens at this and other localities in Fife. In 1924, I gave an account of the crinoid occurrences at Penton Linns on the Scottish border, the genus *Woodocrinus* being a conspicuous member of the fauna found there. So far, these appear to be all the records of the genus in the Scottish Carboniferous rocks. A few years ago, however, it came to my notice that the late Adam Whyte had collected three specimens, which I regarded as a species of *Woodocrinus*, from the Lower Limestones of the Garpel Water section near Muirkirk, and through the kindness of Professor Gibb of the University of Aberdeen, to which institution the specimens were presented, I am able to describe them here. Formerly, Wachsmuth and Springer referred certain American forms to *Woodocrinus*, but the late Dr. Springer thought this arrangement was wrong and should be disregarded, as he had himself done for a long time (1926, p. 77). The Scottish species now to be described or discussed are: *W. liddesdalensis* sp. nov., *W. whytei* sp. nov., *W. gravis* sp. nov., and *W.* cf. *expansus* de Kon.

(1) *Woodocrinus liddesdalensis* sp. nov.)

1924. *Woodocrinus macrodactylus* de Kon., J. Wright, Geol. Mag., LXI, 270–9, Pls. XIII and XIV.
1924. *Woodocrinus* cf. *macrodactylus* de Kon., J. Wright, Geol. Mag., LXI, 270–9, Pls. XIII and XIV.
1935. *Woodocrinus* cf. *macrodactylus* de Kon., J. Wright, Geol. Mag., LXXII, 207.

Plate VII, Plate VIII, Fig. 3; Text-figs. 1 and 2.

Diagnosis.—A large species; cup, turbinate; IBR, one; IIBr, six to thirteen; IIIBr, eighty to one hundred or more; brachials moderately rounded, short, with parallel sutures; arms tapering, long; column round, nodular, tapering, cirri absent in proximal region, but numerous distally.

Holotype.—J. Wright Collection, No. 2925*a*, specimen on left of slab (Pl. VII).

Paratypes.—J. Wright Collection, Nos. 2925*b*, specimen on right of slab, Pl. VII; 2202, 2195, 2177, 1092, 2301.

Locality.—Penton Linns, Liddesdale, Roxburghshire.

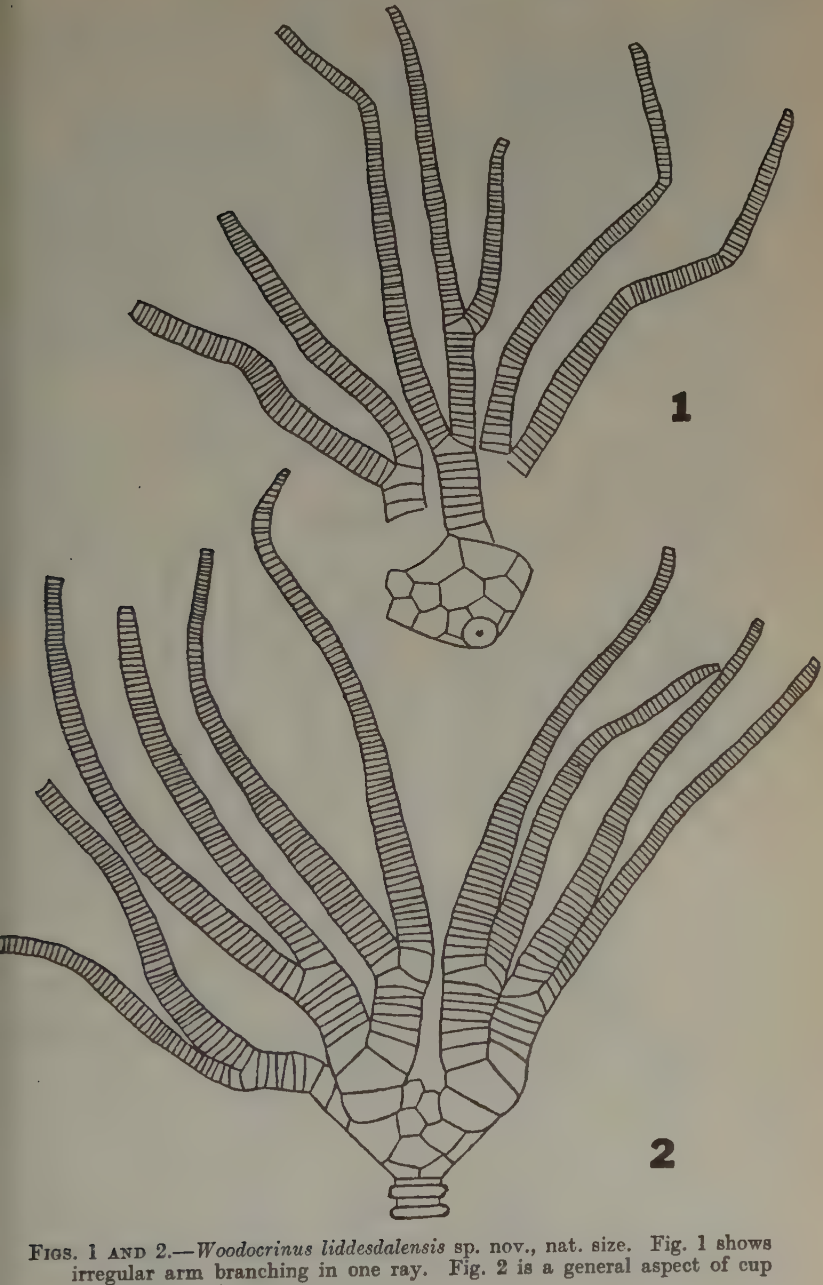
Horizon.—Lower Limestone Group.

Dimensions of Holotype.—Total length of crown with column, approx. 17 inches (428 mm.); length of column, approx. 13½ inches (341 mm.); diameter of column at proximal end, 7·4 mm., at distal end, 4·2 mm.; length of IIIBr, 70 mm.; number of IIIBr, 83; number of IIBr, 9, 10, and 11; height of cup, 8 mm., width across RR at top 17·5 mm., at base 7 mm.

Affinities.—Near to *W. macrodactylus* de Kon., but with flatter brachials, longer and more slender arms.

Remarks.—The total number of nearly complete examples of *Woodocrinus* from Penton Linns in my collection, some of which have a considerable part of the column in position, comprises over twenty-five individuals, and of these twenty-one belong to the species under consideration. I have made a careful examination and compared them with all the figures and specimens of *W. macrodactylus* to which I have had access. These include many specimens in the York Museum, eight in the Royal Scottish Museum in Edinburgh, and two in the Kelvingrove Museum in Glasgow.

In the paper of 1924 already cited, it was noted that the most abundant species at Penton Linns agreed fairly well with *W. macrodactylus*. Indeed, from its general habitus there seemed good reason for thinking that the species was the same. After the publication of that paper, however, I was enabled to collect other specimens from the locality, thanks to the generosity of the late Duke of Buccleuch, who, through the good offices of his factor, Mr. Milne Home, gave special facilities to explore the crinoid bed further into the river bank. A study of this additional material, together with the earlier specimens now better cleaned and developed, convinces me that, while this species is very similar to *W. macrodactylus*, it differs from it in several respects and notably in the greater length of the rays. These features are persistent throughout all the specimens and are not confined to one or two individuals. The brachials also are not so rounded in section and are rather narrower, so that, with the greater length of the crown as a whole, the appearance of this crinoid is not so heavy and short as that of a typical *W. macrodactylus*. It may be noted here that all the specimens from Penton Linns are flattened in the shale and in most cases show the dorsal aspect. In a few, however, the ventral surface is uppermost. (Compare Geol. Mag., LXI, 1924, Pls. XIII and XIV, and present paper Pls. VII and VIII.) The ventral sac is not preserved in any specimen and, as in the Richmond species,



Figs. 1 and 2.—*Woodocrinus liddesdalensis* sp. nov., nat. size. Fig. 1 shows irregular arm branching in one ray. Fig. 2 is a general aspect of cup and arms.

one can only make comparisons from shape of cup and structure of the arms. Fortunately these elements are well preserved in all specimens, although since the arms seem to have been more or less spread out at the time of entombment the cup, while remaining uncrushed, is usually pressed down among the lower brachials. It thus happens that it is seldom possible to see the complete circlet of rays in the lower part of any crown, only two, three, or four may be visible in their entirety and sometimes the anal area of the cup may be concealed from view. Nevertheless, taking the specimens as a whole, all these features can be satisfactorily made out and from the number of secundibrachs and tertibrachs that can be counted it is clear that the greater length of the rays in the Penton form is correlated with an increase in the number of these plates, and is not due to any lengthening of the brachials themselves. This is borne out by the details and statistics given below.

NUMBER OF IIBR IN LEFT AND RIGHT RAMI OF THE RAYS IN *W. liddesdalensis*.

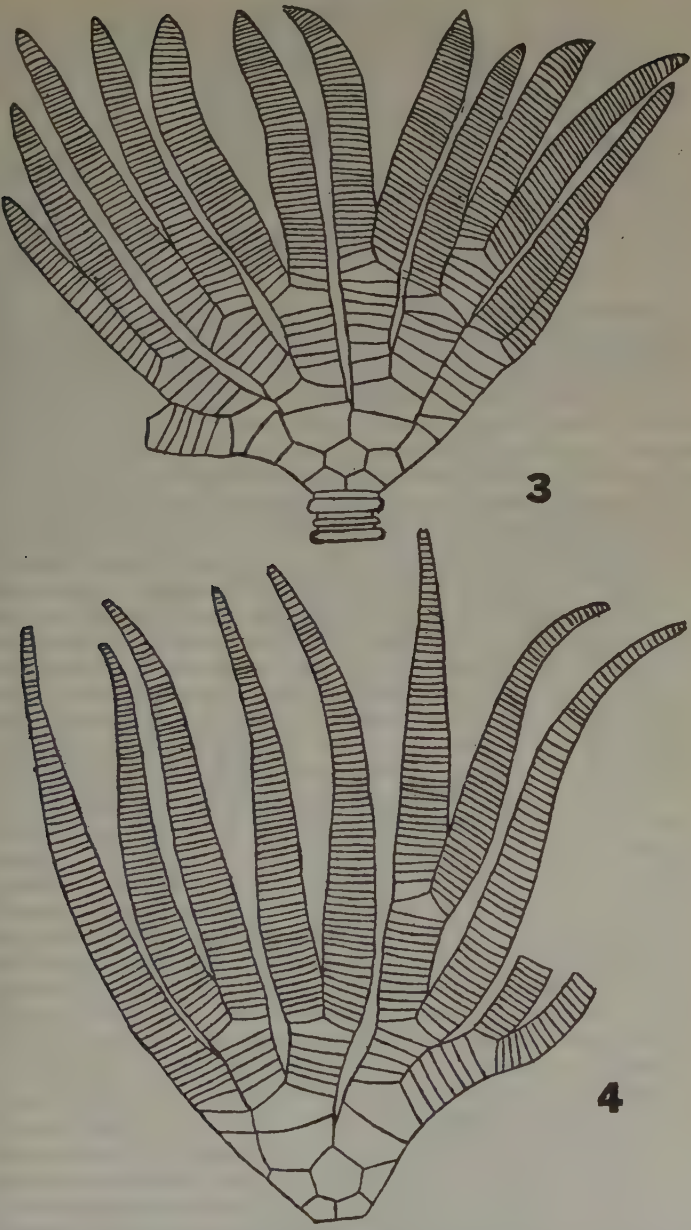
Specimen No.	Left post. Ray.		Left ant. lat. Ray.		Anterior Ray.		Right ant. lat. Ray.		Right post. Ray.	
	L.	R.	L.	R.	L.	R.	L.	R.	L.	R.
2925*a*				10	13	12	9	11	12	9
2925*b*			9		11	9	10	10		
2202	8	8	8	8	8	8	15	8		
2301		7			8		8	8		
1092	8	7	7	8					8	6
2197	6	6							6	6
2205		8			8		9	8	8	7
2104							8	8	8	6
2177	7	6			8	7	8		7	7
1094	8	9				9				

POSITIONS NOT ASCERTAINED.

2195	8	8	6	7		6
2276		9	9			8
2275	8	8	8			
2176		8	8			8

LENGTH AND NUMBER OF IIIBR IN TYPICAL SPECIMENS OF *W. liddesdalensis*.

Full length of crown.	*Length of IIIBr.*	*No. of IIIBr.*
mm.	mm.	mm.
100·8	76·3	84
114·5	89	103
101·6	76	80
96·4	68	93
95·2	71·5	83
95·6	75	78
99	70	80



Figs. 3 and 4. *Woodocrinus macrodactylus* de Kon., nat. size. Fig. 3 from a specimen in the Yorkshire Museum. Original of Fig. 4 in the Royal Scottish Museum. Both specimens show the occasionál irregular branching in one ray.

In *W. macrodactylus.*

Full length of crown.	*Length of IIIBr.*	*No. of IIIBr.*
mm.	mm.	mm.
85·6	51·9	70
64·5	46·6	54
64·6	49	
76·7	47	48
74	47·6	60
74·8	44	40
64·5	42	45
76	53	58

It will be noted that the lowest number of secundibrachs in the Penton species is six, and I have seen nothing below this. Eight is a common number, and they sometimes range up to twelve and even to fifteen. In *W. macrodactylus* the numbers are four to eight, although I have observed one specimen with as many as ten and fourteen in one ray. These latter, however, seem to be very exceptional, and six seems to be the common number. As to tertibrachs in *W. macrodactylus* I have counted these in various specimens and they rarely exceed sixty. Probably seventy or seventy-five is the maximum. In the Penton form it is quite usual to find these plates running to 80 and 90, and even 100, and in one example with a length of 89 mm. they exceed this. In de Koninck's figure of *W. macrodactylus*, and in the majority of specimens I have seen, the branching of the rays is very regular, i.e. the sixth or eighth secundibrach is axillary and supports two tapering rami of tertibrachs which do not bifurcate again. Among the specimens I have examined are two which show a slight variation from this (Text-figs. 3 and 4). Fig. 3 is drawn from a specimen in the York Museum, and Fig. 4 from one in the Royal Scottish Museum. We see here a tendency to multi-branching which, so far as *Woodocrinus* is concerned, reached its highest degree in *W. expansus*. There can, of course, be no doubt that the regular way in which the arms branch is a distinctive feature in the majority of specimens of *W. macrodactylus*, but from the two instances given one cannot help thinking that if all the specimens of this species could be examined other cases of this slight irregularity of the arm branching might be noticed. A specimen figured by Baily (*Characteristic Brit. Foss.*, pl. 36, fig. 5, 1875) also shows irregular branching in the outer ramus of one ray. As with *W. macrodactylus* the Penton specimens have also very regular arm branching, but in this case the rule is that the eighth or tenth secundibrach is axillary and supports two rami of from eighty to a hundred tertibrachs which give off no branches. It is interesting, however, to note that in one specimen at least there is a slight variation from this, the seventeenth tertibrach in the right ramus of the ray in the centre of Text-fig. 1 being axillary and an extra arm is given off here. This is a parallel case to the two just noted in *W. macrodactylus*. (The specimen from which this figure is drawn was illustrated in Geol. Mag., LXI, 1924, specimen with column on right of photograph.)

The Cup in *W. liddesdalensis.*

In the Penton specimens, the cup is of the same general shape and plan as in *W. macrodactylus.* It seems, however, to be somewhat smaller and is of a characteristically low turbinate form, easily recognizable in detached specimens. It is usually more than two times wider than high with prominent though rather small infra basals. The anal area is normal. I have seen no deviation from this, although one notes that RA may be smaller in one specimen than in another, and that the anal X may be a little higher or lower within the limits of the cup. There appear to be no transitional stages as in the *Eupachycrinus* series (Wright, Geol. Mag., LXIII, 1926, 145–164).

The Column in *W. liddesdalensis.*

According to Dr. Springer (*Zittel-Eastman*, 1913, p. 223) the column in *Woodocrinus* is short, has few cirri, and tapers away distally. This seems to hold good for *W. macrodactylus.* In the Penton specimens the column appears to have been relatively longer. In mature specimens, such as those shown on Pls. VII and VIII, it is preserved to a considerable length. None show it complete, although on two slabs it measures about 14 inches and on another over 16 inches. One young specimen, however, has a crown 54 mm. in height and a complete column 159 mm. (approximately 6½ inches) long. At the cup its diameter is 3·6 mm. ; it remains this thickness for 22 mm. and then swells out to 5 mm. after which it tapers away towards the distal end. Traces of cirri are observable only in the latter region. At the extremity it is rather less than 1 mm. in diameter. The nodular and tapering character of this column is very similar to that of the typical *W. macrodactylus* as figured by de Koninck ; but in all the other Penton specimens, which are much larger, while the column has the same more or less nodular character, it does not swell out in the central region, as in this small specimen. It tends rather to narrow gradually from the cup downwards and is alway definitely thinner at the distal end. Whether it afterwards tapers to a point cannot be positively stated. As a rule there are few cirri present on the long columns, but many of the thicker nodals show the joint faces for the attachments of these elements. They are more noticeable on some columns than on others. The specimen shown on Pl. VIII, Fig. 3, shows these joint faces well and the specimen on left of Pl. VII has several of the cirri in position near the distal end. This latter feature is also well seen on the specimen of the species already figured in Geol. Mag., LXI, 1924, Pl. XIV. There seem to have been no cirri near the cup, and it is usually 3 or 4 inches below this position before cirriferous columnals can be detected. On these the joint faces are very small and the cirri here and for some distance downwards were thin and apparently short. Nearer the distal end, however, the joint faces are larger and the cirri in this region were thicker and longer. As they are traced along the column, the cirriferous nodals appear at more or less regular intervals. They become appreciably thicker and are pronouncedly so towards the distal end. They are always separated by a varying number of columnals, usually three or four, which bore no cirri. Towards the distal end especially, the cirriferous nodals, owing to the relatively thinner columnals between them, at once catch the eye and impart a distinctive appearance to the column as a whole. From the foregoing, it is clear that cirri were quite numerous on the greater part of the column in *W. liddesdalensis*. In this respect it would appear that our species also differs from *W. macrodactylus*, but the evidence here is scanty since I have seen few specimens of the latter with columns and none with any so long as in *W. liddesdalensis*.

(2) *Woodocrinus whytei* sp. nov.

Plate X, Fig. 4.

Diagnosis.—A moderate-sized species; cup elongate, more or less conical; IBr one; IIBr, six to eight, supporting two tapering rami of IIIBr; IIIBr, ninety or more with length of 59 mm.; brachials flat, quadrangular with parallel sutures; full length of crown in holotype, 89 mm.; height of cup, 14·6 mm.; width at top (estimated), 17·5 mm.

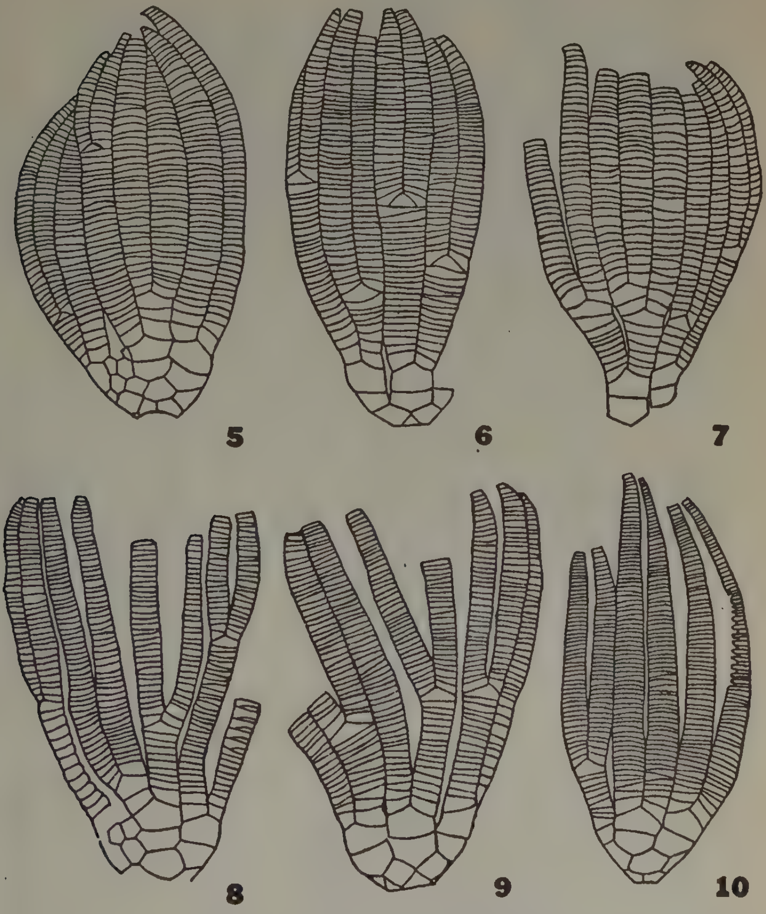
Holotype.—Geological Department, University of Aberdeen, Whyte Collection, Pl. X, Fig. 4.

Paratypes.—University of Aberdeen, two specimens.

Locality.—Garpel Water, Muirkirk, Ayrshire.

Horizon.—Lower Limestone Group.

Remarks.—This species differs from all other known species of *Woodocrinus* in the form of the cup and the flat nature of the arms. The cup is much more elongated than in a typical *Woodocrinus*, in fact it has more the characters of a *Pachylocrinus* It is also reminiscent of such a form as *Zeacrinus bursaeformis* White (Springer, 1926). The anal area is normal. It is not seen in the holotype, but it can be detected in the smaller of the two paratypes. The arms, though rather narrower, are not unlike those of *W. liddesdalensis*, except that the brachials are more flattened in section, in this respect like those of a *Zeacrinus*. The branching is very regular, at any rate it is so in the only three known specimens. I have been unable to ascertain the exact whereabouts of the bed from which Mr. Whyte collected the specimens, but from conversation with Mrs. Whyte, who often accompanied her husband to the Garpel Water, there is no doubt they were obtained from one of the Lower Limestones. The specimens appear to have been thrown out during quarrying operations. The column is preserved for a short distance in the holotype, but is somewhat abraded. It is of an alternating character, but apparently with less pronounced nodes than in *W. macrodactylus* or *W. liddesdalensis*.



Figs. 5–10.—*Woodocrinus gravis* sp. nov. Drawings of four specimens to show the variability of the arm branching. Figs. 5 and 6, both sides of the same specimen. Fig. 7, a specimen showing only the ant. and left ant. lat. rays. Figs. 8 and 9, both sides of another specimen, and Fig. 10 a specimen showing two rays which do not fork after the first primibrach. All from No. 3 Bed, Invertiel, except Fig. 10, which is from Roscobie. $\frac{7}{8}$ nat. size.

(3) *Woodocrinus gravis* sp. nov.

Plate VIII, Fig. 1; Plate IX, Figs. 1–3; Plate X, Figs. 1 and 9; Text-figs. 5–21.

Diagnosis.—A moderate-sized species; cup turbinate, over two times wider than high, anal area normal; arms short, heavy, and rounded, branching very irregular.

Holotype.—J. Wright Collection, No. 429, Pl. IX, Figs. 1 and 3; Text-figs. 5 and 6.

Paratypes.—J. Wright Collection, Nos. 430, 1084, 2278.

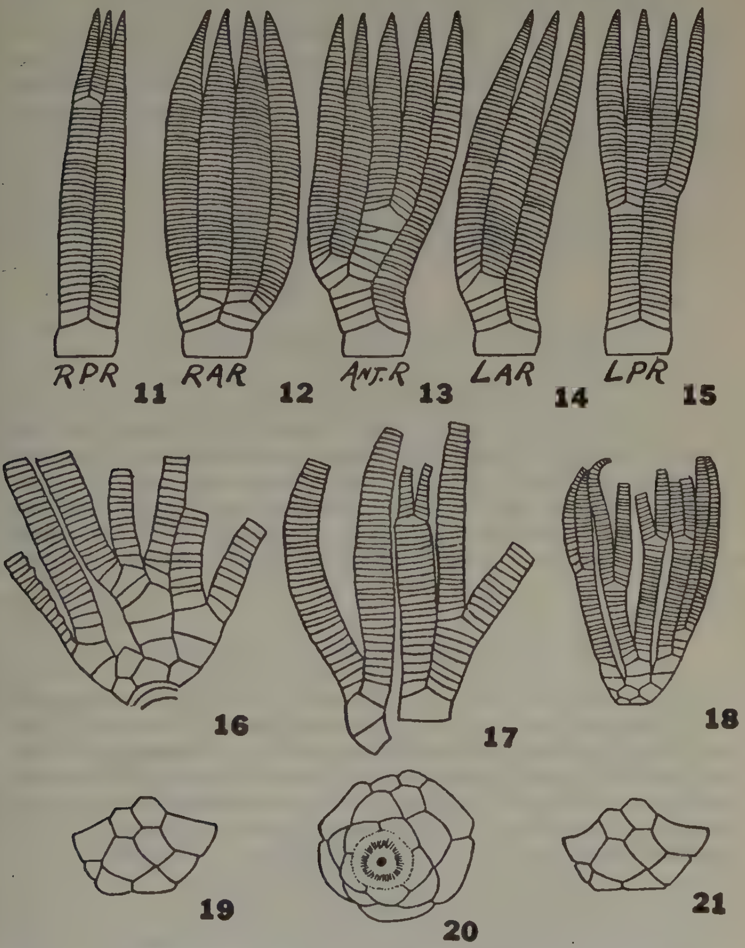
Locality.—No. 3 Bed, Invertiel.

Horizon.—Lower Limestone Group.

Dimensions of Holotype.—Full length of crown, 59·5 mm.; height of cup, 6·4 mm., width across RR at top, 13 mm.

Remarks.—I have collected thirty-three specimens of *Woodocrinus* from the Fife limestones, the majority of which consist of rather crushed and imperfect crowns. Ten of these are from Roscobie, the others from No. 3 Bed, Invertiel. They range from very small specimens up to mature forms, such as those shown on Pl. VIII, Fig. 1, Pl. IX, Figs. 1–3, and Pl. X, Fig. 1. Nearly all are incomplete, showing one, two, or three rays, some in part only, but three of the crowns exhibit the full arm structure. Text-figs. 5 and 6 represent one which is perfectly preserved and taken as holotype, Text-figs. 8 and 9, another, and the third, is represented by Text-figs. 11–15. It will be observed that the arm branching is quite different in these three specimens and each might be taken for a distinct species. The same irregularity, however, is found to characterize all the other specimens scarcely two of which are exactly alike. It is clear, therefore, that the arm branching does not help as much in the discrimination of these specimens and for lack of any other criteria I am compelled to group them all under one species. It is, of course, possible that more than one species is represented in the collection since several specimens are fragmentary and give comparatively few details. The evidence available, however, precludes this view.

At first sight the specimens have some resemblance to *W. macrodactylus*, with which they agree in the short, heavy nature of the arms, but the branching at once marks them off from that species. So far as my knowledge goes, the typical *W. macrodactylus* has not been found in the Fife rocks, nor have I ever seen any specimens which could be compared with any of the other described species of *Woodocrinus*. Instead, we have these specimens which, while simulating *W. macrodactylus* to a certain extent, are in direct contrast to it in the extreme irregularity of the arm branching. The text-figures give some indication of this, and it may be noted that no fixed rule seems applicable to any particular ray, the secundibrachs and tertibrachs always varying. The same is to be observed in less complete specimens, an added difficulty here being that one cannot in every case be sure about the position of the ray or rays that may be exposed. In Text-figs. 7 and 10, for instance, and in the small specimen, Text-fig. 18, the positions are uncertain, yet, allowing for this, the branching cannot be matched in any of the complete crowns. Unfortunately, nearly all the smallest specimens are incomplete, especially as to the distal region of the arms. As might be expected, however, the branching in very young specimens



Figs. 11–21.—*Woodocrinus gravis* sp. nov. Figs. 11–15, the complete circle of rays in one specimen. Figs. 16 and 17, two sides of another specimen. Fig. 18, a small specimen. Figs. 19 and 21, side views of cups from posterior. Fig. 20, basal view of cup. All from No. 3 Bed, Invertiel, except Figs. 16 and 17 from Roscobie. Figs. 11–18, approx. ⅞ nat. size. Figs. 19–21, approx. 1⅓ nat. size.

is less complicated and can be seen in one or two better preserved examples where each ray consists only of a double series of secundibrachs. It was at first hoped that a connected series showing growth stages might be worked out, but so far this has been found impossible. Later, something may be done in this direction. Text-fig. 18 gives some idea of the branching in a medium sized specimen. An interesting feature is shown in another and larger specimen, Text-fig. 17 (also Pl. IX, Fig. 2). Here, the left ramus of the ray on right of figure, up to the twentieth secundibrach, is quite normal. The twenty-first is axillary and abnormally small and supports two tiny tapering rami of tertibrachs. The whole appearance here suggests that the arm was broken during life and a more or less successful attempt has been made to repair the injury.

The cup in the mature forms is shown on Pl. X, Fig. 9, and Text-figs. 19, 20, and 21. In general character it is very similar to that of *W. macrodactylus*. The column has only been noted in a somewhat scattered and fragmentary condition, but so far as observed, it is of the usual *Woodocrinus* type.

(4) *Woodocrinus* cf. *expansus* de Koninck.

1924. J. Wright, Geol. Mag., LXI, 272, Pl. XV.

The specimen from Penton Linns referred to this species, was illustrated and discussed in paper noted above. Little can be added to the information then given since no more specimens have been obtained. The specimen probably belongs to a new species, but that is all one can at present say about it. In the paper cited I suggested that if this specimen should turn out to be new it might be called *pentonensis*.

PACHYLOCRINUS Wachsmuth and Springer.

Following the method of Dr. Springer (1926, p. 69), I am placing under *Pachylocrinus* the two species noted below. Formerly, these would have been grouped under *Poteriocrinus*. The Scottish species restricted to the latter genus will be discussed in a future communication, along with one or two others probably referable to *Pachylocrinus* but not yet worked out. The present specimens have been in my collection for a long time and opportunity is now taken to place them on record. In assigning them to new species, however, I do so with some diffidence. They are clearly different from any described British species, but it is a matter of the greatest difficulty to determine their relationship to American forms, of which there is a formidable number described in scattered publications and referred to such genera as *Poteriocrinus*, *Scaphiocrinus* or *Scytalocrinus*, etc. Although I have seen many of these works, it is possible some have been missed. Also, the ventral sac, upon which the characters of some of these species are based, is not preserved in our specimens, and is only now represented by a few detached plates at the termination of the arms.

(5) *Pachylocrinus tielensis* sp. nov.

1912. *Poteriocrinus* cf. *conicus* Phillips. J. Wright, *Trans. Edinb. Geol. Soc.*, x, pt. i, p. 58, pl. vii, fig. 4. *ibid.*, xi, pt. iii, p. 288, 1925.

Plate IX, Fig. 4, Text-figs. 22–4.

Diagnosis.—A robust species; cup broadly conical; anal area normal; IBr, one; IIBr, variable, six to twelve; plates smooth; brachials, more or less cuneate, interlocking, tending to biserial distally.

Holotype.—J. Wright Collection, No. 2190. Text-fig. 22.

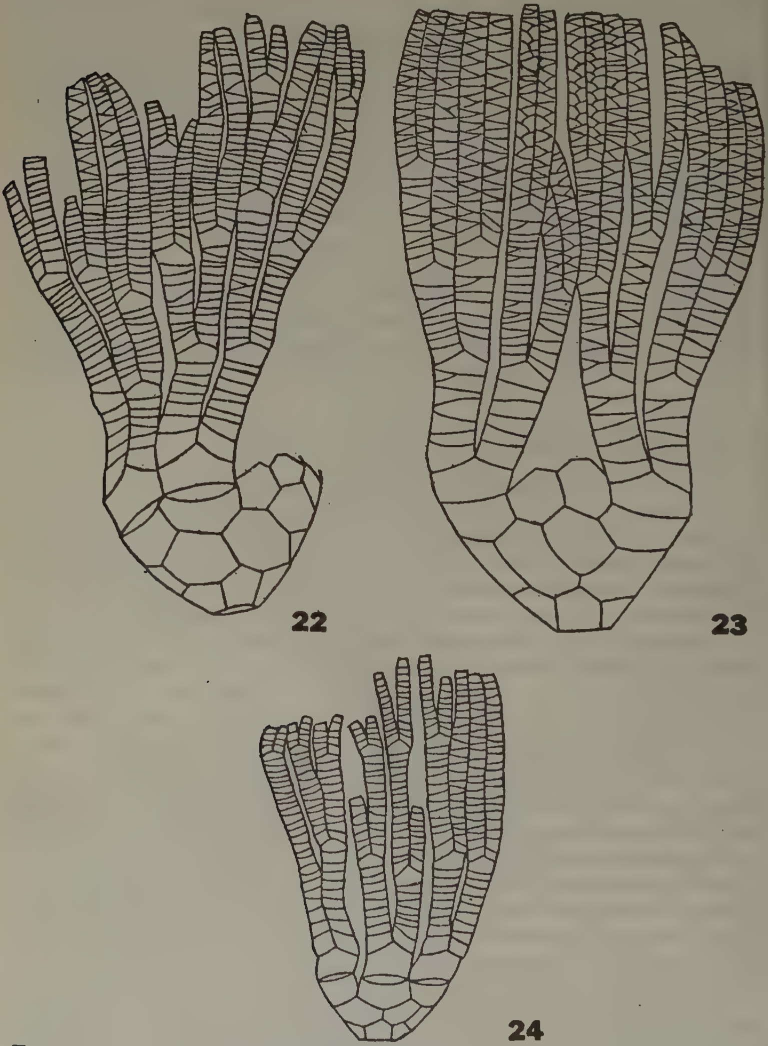
Paratypes.—J. Wright Collection, Nos. 96, 121, 2200.

Localities.—No. 3 Bed, Invertiel, Roscobie, Charlestown, Bishop Hill, Auchenskeith, Bankend.

Horizon.—Lower Limestone Group.

Dimensions of Holotype.—Full length of crown, 87 mm.; height of cup, 18·4 mm., width, 21·5 mm.

Remarks.—In Fife, cups of this species have been found at Invertiel, Roscobie, and in the Seafield Tower limestone, etc. A cup from Auchenskeith, Ayrshire, and a bundle of arms, minus the cup from Bankend, Lanarkshire, both in the Dunlop Collection, Royal Scottish Museum, probably also belong to this species. Such cups, by themselves, are very difficult to place since, although generally larger, they more or less resemble other species of *Pachylocrinus* found in Britain, Russia, or America. They come nearest perhaps to British species and have a more striking resemblance to *P. conicus* Phillips than to any other. In fact, in the past some of our cups have been provisionally referred to this species. Apart, however, from their usually larger size, they differ from it in that they do not taper so much and are broader. In *P. conicus* for example the width across the radials is generally about the same as the height of the cup; whereas in our species the width is always much more than the height. The arm structure of *P. conicus* is unknown. That of our species is shown in detail in some crowns from No. 3 Bed, Invertiel, and indicated in Text-figs. 22–4. As may be noted, the branching is somewhat irregular, but the most noticeable feature perhaps is the tendency of the brachials to interlock. This is specially marked in the distal region of the rays. In the holotype, Text-fig. 22 and in the smaller of the two paratypes, Text-fig. 24, this tendency is not so prominently seen as in the larger paratype, Text-fig. 23, where, distally, certain parts of the arms are biserial in character. Interlocking of the brachials is well known in other crinoids, e.g. *Culmicrinus elegans* Wachsmuth and Springer and *Ulrichicrinus oklahoma* Springer (Springer, 1926, Pl. XVIII, Fig. 1; Pl. XX, Fig. 1) also in *Pachylocrinus* (*Poteriocrinus*) *genistus* Miller and Gurley and *P. scopae* M. and G. (Miller and Gurley, 1890, pl. vii, figs. 3 and 2). Our species seems to come very close to the last named



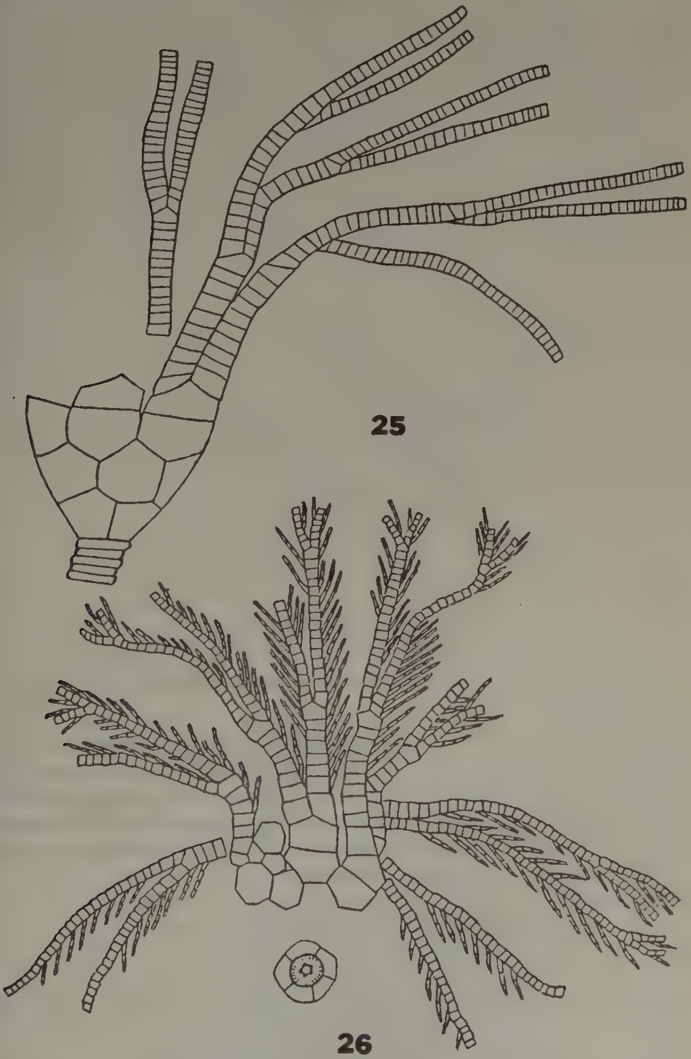
Figs. 22–4.—*Pachylocrinus tielensis* sp. nov. from No. 3 Bed, Invertiel. Approx. $\frac{7}{8}$ nat. size.

which, however, appears to be a smaller species altogether. The interlocking and biserial character of the brachials is also less pronounced in this and the other species mentioned.

(6) *Pachylocrinus dunlopi* sp. nov.

Plate VIII, Fig. 2; Text-figs. 25–7.

Diagnosis.—Cup, conical; anal area, normal. Arms long, tapering; IBr, one; IIBr, six to ten; plates, smooth; column, round.



Figs. 25 and 26.—*Pachylocrinus dunlopi* sp. nov., from Penton Linns. Approx. $\frac{7}{8}$ nat. size.

Holotype.—J. Wright Collection, No. 2204. Text-fig. 26.
Paratypes.—J. Wright Collection, Nos. 2210, 2175.
Locality.—Penton Linns, Liddesdale.
Horizon.—Lower Limestone Group.

Remarks.—This species is represented by three specimens (Pl. VIII, Fig. 2; Text-figs. 25–7). In general aspect, it resembles *P. longidactylus* Austin and perhaps *P. rugosus* Grenfell, both from the Lower Carboniferous of the Bristol district, but it differs from these species in having only one primibrach, and in probably attaining a larger size. It has rather slender and long arms with at least three bifurcations at fairly regular intervals in each ray. Text-fig. 25 represents the most mature specimen and the cup here, although smaller, is not much different from that of *P. tielensis*. The general aspect and the arm structure are, however, obviously quite dissimilar. Probably the species occurs in Fife, but specimens are rare. I have a small crown from Roscobie which may belong to the species. The column is preserved for some distance in two of the specimens. It is round and composed of alternating columnals, not contrasting greatly in diameter and of moderate and uniform thickness, in this respect not unlike that of *P. ramosus* Miller and Gurley, although otherwise our species is quite different.

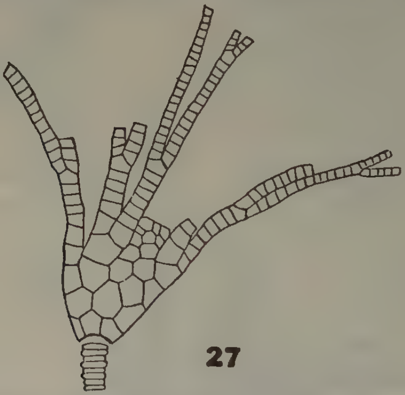


FIG. 27.—*Pachylocrinus dunlopi* sp. nov. from Penton Linns. Approx. ⅞ nat. size.

TRIBRACHIOCRINUS McCoy.

(7) *Tribrachiocrinus caledonicus* sp. nov.

1917–18. *Tribrachiocrinus* McCoy. J. Wright, *Trans. Geol. Soc., Glasgow*, xvi, pp. 369 and 387.

Plate X, Figs. 3, 8, 10, 11, and 12.

Diagnosis.—A small species; cup somewhat flat or shallow, bowl shaped; IBB, usually five, sometimes fused, sunk in concavity and invisible in side view; BB, five; three RR of normal width, the other two narrow and little more than half as wide, on which is fused a small triangular brachial curved over on top of cup; plates with vermiculate rugose ornamentation.

Holotype.—J. Wright Collection, No. 2072*a*. Pl. X, Fig. 3.

Paratypes.—J. Wright Collection, Nos. 2072*b–m*.

Locality.—Calcareous shales (No. 4 limestone), above pink false bedded sandstone, shore at Seafield Tower near Kirkcaldy.

Horizon.—Lower Limestone Group.

Dimensions of Holotype.—Diameter of cup across RR, 11·3 mm.; height, 5 mm.; width of normal RR at top, 5 mm.; width of narrow RR at top, 2·8 mm.

Remarks.—*Tribrachiocrinus* has only hitherto been found in Australia and Tasmania, the described species being four, viz. *T. clarkei* McCoy, *T. corrugatus* Ratte, *T. granulatus* R. Eth. Jr., and *T. ornatus* R. Eth. Jr. (Etheridge, Jr., 1892, pp. 82–97, Pls. XII–XXI). No other records are known, so that the present species is the first to be noted in the northern hemisphere. The discovery of *Tribrachiocrinus* in the Fife rocks really dates from 1917 when I recorded three cups which I had sent to Dr. Bather, who hoped to describe them (1917–18, p. 387). Unfortunately, time was never found for this and on his death in 1934 the specimens were returned to me. In the interim I had found another nine cups, so that the total number of specimens now in my collection is twelve. In making a comparison between our cups and the Australian species one finds a little difficulty owing to the fact that the latter are mainly in the form of moulds or casts. Even so, it is perfectly evident that the Fife cups belong to a distinct species, the nearest Australian form apparently being *T. granulatus*, and it differs in many details. The chief differences in the Fife cups are: (1) Small size; (2) the IBB circlet usually consists of five plates, not three, as in the Australian species, and these are sunk in a deep concavity often with straight or steeply sloping sides. In three of the Australian species (*T. clarkei*, *T. corrugatus*, *T. ornatus*) it is concave and saucer-shaped with gently sloping sides. (3) The shallow nature of our cups. *T. granulatus* seems to have a shallow cup but, apart from its larger size, the granular ornamentation and the form of the IBB circlet are markedly different. The figures on Pl. X give some indication of the main characters of our species. Fig. 8 shows the surface ornamentation which is characteristic, but is more marked on some cups than on others. This figure and Fig. 2 are dorsal views. The appearance here is not unlike some cups of *Eupachycrinus calyx* (McCoy), but the true relationship to *Tribrachiocrinus* is at once apparent when the cups are viewed from above (Pl. X, Figs. 3 and 10). The articular facets on the three normal radials are always well seen, as are also the two small triangular brachials which are continuous with and appear in most cases to be fused to the narrow radials. Except in three cups I find it impossible to detect the suture lines between these brachials and radials In two of the specimens the suture lines are at the same level as, or slightly above, the normal radials, but in the third the narrow radials curve well over the top of cup inwards and the suture lines here are considerably beyond the rim of the normal radials. In this case the two triangular brachials are very small. I cannot see any evidence that these brachials supported arms as was contended by Wachsmuth and Springer. In most cases, they curve over the top of the cup as if they had been immovably fixed in this position, and it is hard to see how they could have functioned as axillary plates. The facets on the normal radials are of the full width, abutting at the sides close up against the triangular faces so that other than those borne by the normal radials there could not have been much, if any, room for additional arms. In all cups, the " non-arm-bearing " radials are very narrow compared with the normal radials. They are little more than half as wide and in one or two cases are even less. So far as can be judged from Etheridge's figures this feature is more marked in our species than in the Australian forms. The anal area in all twelve cups is of the normal type (Pl. X, Fig. 12). As might be expected, there are some slight modifications from this, but the plan always remains the same. As a rule the RA is a large, well-defined pentagonal plate with the upper surface more or less in line with the right post radial. Two of the cups show abnormalities in the number of basals. In one very small specimen these plates only number three owing to the fusion of posterior and left posterior basals. The other has only four basals. Here the fusion is between right posterior and right anterior basals. In a few cups the suture lines between the IBB are easily seen, and in these cases the circlet consists of five plates. In others, however, suture lines are difficult to detect owing to the steep and sometimes perpendicular sides of the cavity occupied by the IBB. In one or two it seems evident that the plates are fused.

ULOCRINUS Miller and Gurley.

(8) *Ulocrinus doliolus* sp. nov.

1934. *Hydriocrinus* sp. J. Wright, Geol. Mag., LXXI, p. 244.

Plate IX, Fig. 5; Text-figs. 28–32.

Diagnosis.—Cup elongate, slightly constricted at top; IBB circlet prominent, over one-third height of cup, only slightly tapering towards base; RR relatively short; anal area as in normal form of *U. globularis* with large RA surmounted by two small plates; arms, five, long, brachials, narrow and cuneate; pinnules, short; length of arms in holotype, 96 mm., height of cup 7 mm.

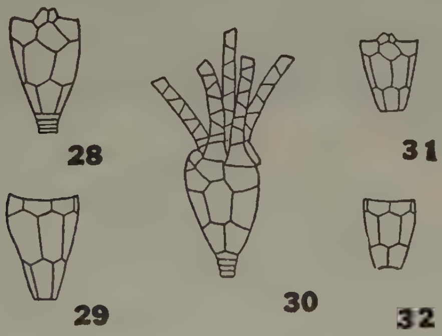
Holotype.—J. Wright Collection, No. 1093. Pl. IX, Fig. 5.

Paratypes.—J. Wright Collection, two cups, No. 2280 *a* and *b*; one cup in Collection of Geological Department, St. Andrew's University.

Locality.—Encrinite bed, St. Andrews.

Horizon.—Calciferous Sandstone Series.

Remarks.—In 1934, in the paper in GEOL. MAG., cited above, I referred a cup, found by Dr. G. Cumming, in the Encrinite bed at St. Andrews, to Trautschold's genus, *Hydriocrinus*, mainly on the strength of its resemblance to *Hydriocrinus pusillus* of that author (Trautschold, 1879, p. 116). The cup, however, did not show the anal area, and its reference to this genus was based chiefly on the general habitus and somewhat peculiar rather high nature of the infra-basal circlet. It was noticed that the cup in some respects reminded one of the more elongate forms of *Ulocrinus globularis* (de Kon.) which I have dealt with before (1927, p. 353), but the character of the infra-basal circlet at once attracted attention, giving a shape and general appearance to the cup which seemed to agree better with *Hydriocrinus* than with any other known form of *Ulocrinus*. Recently, I have found another two specimens in the Encrinite bed, one a fairly well preserved crown, the other a detached cup, and both fortunately show the anal area (Pl. IX, Fig. 5, Text-figs. 28–32). This feature, in conjunction with the arm structure of the crown, now makes it certain that the St. Andrews species is quite distinct from *Hydriocrinus pusillus* and more nearly related to *Ulocrinus* than I had formerly thought. In *H. pusillus* the anal area is of the more primitive type as usually seen in *Poteriocrinus*, *Eupachycrinus*, and similar genera, i.e. with anal X having a broad junction with post. B and separating RA from left post. R; whereas the St. Andrews species has an anal area not very dissimilar from the typical more advanced plan seen so commonly in the cups



FIGS. 28–32.—*Ulocrinus doliolus* sp. nov. Figs. 28 and 31, cups from posterior; Figs. 29 and 32, cups from anterior. Fig. 30, drawing of specimen on Pl. IX, Fig. 5, to show lower part of arms. Figs. 28–30, nat. size. Figs. 31 and 32, 1⅓ nat. size.

of *Ulocrinus globularis* as found in Scottish rocks, i.e. a large RA joining up with left post. R, and surmounted by two smaller plates. Moreover, the arm structure of *Hydriocrinus pusillus* is uniserial and multi-branching and consists essentially of one primibrach which is axillary and supports two rami that again fork at the eighth or tenth secundibrach. The total number of arms is thus twenty or four to each ray. On the other hand, the St. Andrews species has only five simple uniserial unbranched arms, one to each ray, and although presumably longer, much the same in character as those of *U. globularis*. In fact, it now seems evident that in the character of the arms and plan of anal area the St. Andrews species does not differ much from typical forms of *U. globularis*. There is however, a distinct difference in the shape and general appearance of the cup which marks it off from the latter species, and particularly from the more elongate forms which, as already mentioned, it most closely resembles. In these, the IBB circlet is in the form of an inverted cone with tumid or sometimes even slightly concave sides, tapering rapidly and narrow at the base where it joins the column. In the St. Andrews species, the circlet tapers comparatively little, the sides are nearly straight and the circlet while being wider at the base is also relatively greater in height. This is borne out by measurements given below :—

	Two cups of *U. globularis.*		Two cups of *U. doliolus.*	
	mm.	mm.	mm.	mm.
Height of cup over all	12·7	12·7	12·7	8·6
Width of cup at top	12·4	11	9	5
Height of IBB circlet	3	3	4·7	3
Height of post. B	7	6·9	6	3·7
Width of post. B	6·5	6	3	3
Height of right post. R	4	3	3	2·8
Width of IBB circlet at top	8·6	8·5	6·4	4·5
Width of IBB circlet at base	2·9	2·5	3·3	3·3

The measurements of *U. globularis* are taken from two typical specimens of the elongate variety, and it will be seen that the St. Andrews cups are relatively narrower and have a higher IBB circlet which is correspondingly wider at the base. In shape this circlet may be likened to a small tub or one of the halves of a bisected barrel. This is specially noticeable in the smaller specimens, such as that of Text-fig. 31. A characteristic appearance is thus given to the cups which is rather difficult to convey in words and is not so well shown on Pl. IX, Fig. 5, because the whole cup here is considerably flattened. The infra-basal circlet itself seems to have been readily detached quite intact when the other plates of the cup became dismembered at the time of deposition of shale or limestone. The late James Bennie collected several of these circlets in washed shale from the Encrinite bed (Wright, 1934, p. 245).

They are easily distinguished from similar detached circlets of *U. globularis*, which are occasionally found in washed shale from higher horizons, but have not to my knowledge been found in the Encrinite bed. Taking such facts into consideration there appears good reason for regarding the St. Andrews specimens as a distinct species of *Ulocrinus* closely related to *U. globularis* but differing from it in the form of the infra-basal circlet, the more elongate shape of the calyx in general and probably also in the greater length of the arms. The species is characteristic of the Encrinite bed since, so far as known, it appears only on this horizon of the Calciferous Sandstone Series.

FLEXIBILIA Zittel

LECANOCRINIDAE Springer.

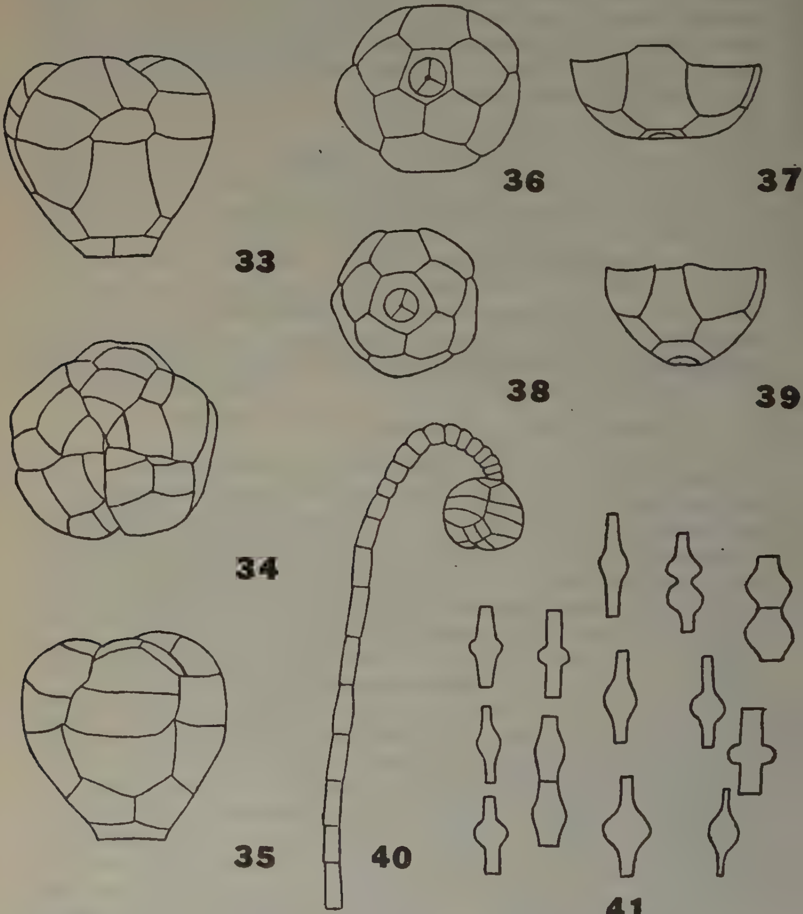
MESPILOCRINUS de Kon. and Le Hon.

(9) *Mespilocrinus* cf. *konincki* Hall.

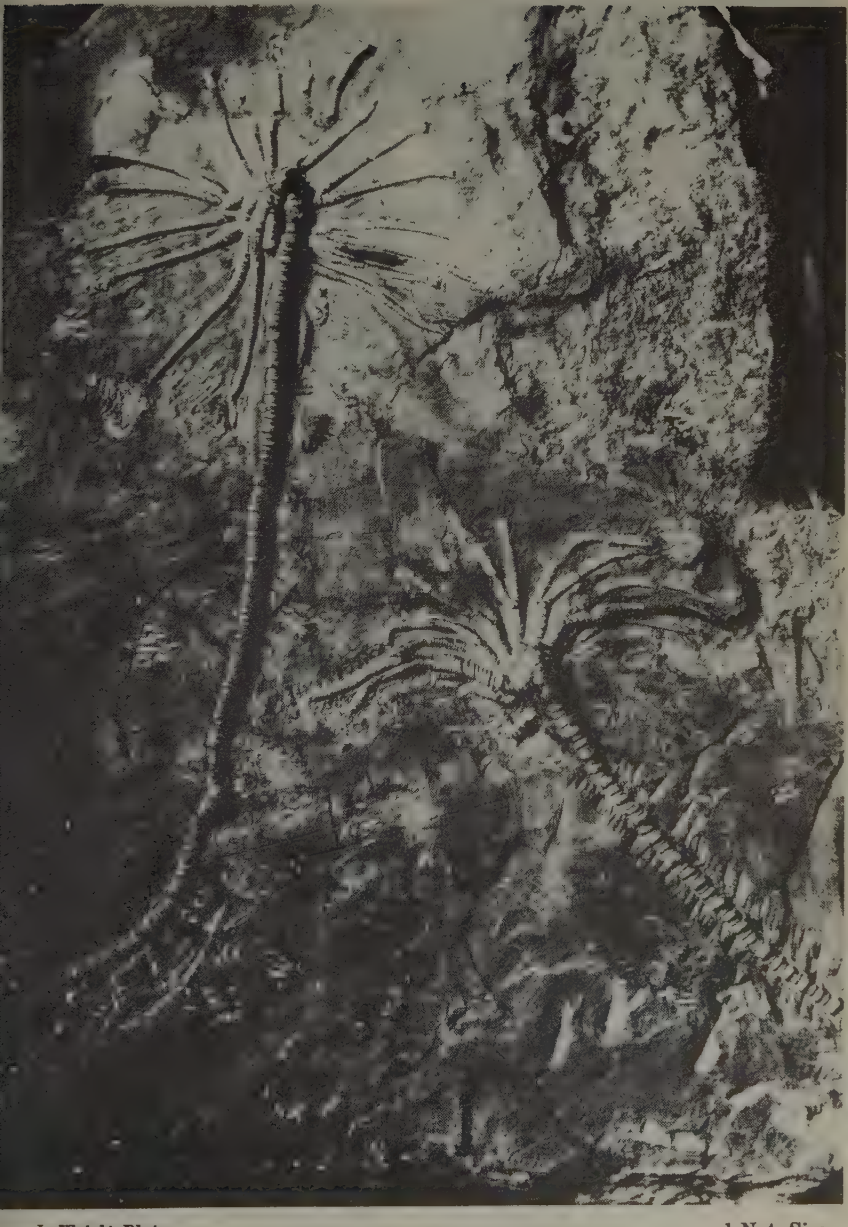
1925. *Mespilocrinus* near *forbesianus* de Kon. and Le Hon. J. Wright, *Trans. Edinb. Geol. Soc.*, xi, pt. iii, p. 288. Geo. Mag. lxxii, 1935, p. 207.

Plate X, Fig. 7 ; Text-figs. 33, 34, 35, 38, and 39.

There are at least two species of *Mespilocrinus* in the Lower Carboniferous Limestones of Scotland, but since the majority of specimens consist of cups only, one finds considerable difficulty in dealing with them. The most abundant form, of which I have fifty-seven cups and three small crowns has been recorded in previous papers as *M.* near *forbesianus* de Kon. and Le Hon. The original number collected far exceeded this total, but I have given many away. In Fife, cups of this type occur at Invertiel, in the Seafield Tower limestone and in the corresponding bed (Zone 33) in the St. Monance section. This species probably also occurs at Carlops in Peebleshire. All these cups are much smaller than the figures of *M. forbesianus* given by de Kon. and Le Hon. (1854, Pl. II, Figs. 1*a–c*), and by Dr. Springer (1920, Pl. V, Figs. 1–3). The largest was found at No. 1 Bed, Invertiel, and measures only 11·8 mm. in width by 7 mm. in height, but the majority are considerably less than this. In shape of cup and in the position of the posterior basal which rises nearly to the level of the radials, there is no doubt that our specimens have a general resemblance to the cup of *M. forbesianus*, but they are also very like the cup of *M. konincki* Hall, which is a smaller species altogether. Dr. Springer mentions (op. cit., p. 194) that there is great difficulty in distinguishing between these two species from cups or crowns alone, and therefore, apart from size, it would seem that the chief and perhaps only difference between them is in the character of the column. So far as the cup is concerned, in the figures of *M. forbesianus* the IBB circlet is somewhat low, though distinctly elevated. The same is the case with *M. konincki*, and with the cups under discussion (Pl. X, Fig. 7, Text-figs. 38 and 39). In size, our cups come nearer to *M. konincki*, but otherwise it is difficult to differentiate between them and either of the species mentioned. One notes

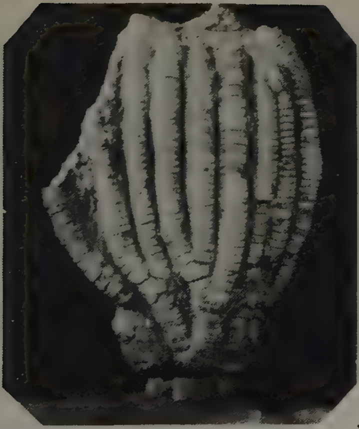


Figs. 33–41.—*Mespilocrinus* cf. *konincki* Hall and *M. depressus* sp. nov. Figs. 33–5, young crown of *M.* cf. *konincki*. Figs. 36 and 37, *M. depressus*, basal and side views of cup. Figs. 38 and 39, *M.* cf. *konincki*, basal and side views of cup. Fig. 40 ? *M. depressus*, crown and column of specimen in Neilson Collection. Royal Scottish Museum. Fig. 41, spindle-shaped columnals of *Mespilocrinus*. All figs. × 3/2, except Figs. 33–5, which are approx. × 3½.

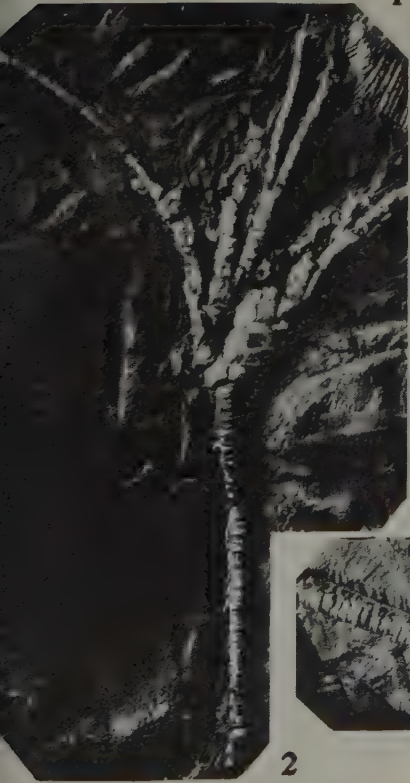


J. Wright Photo. ¼ Nat. Size.

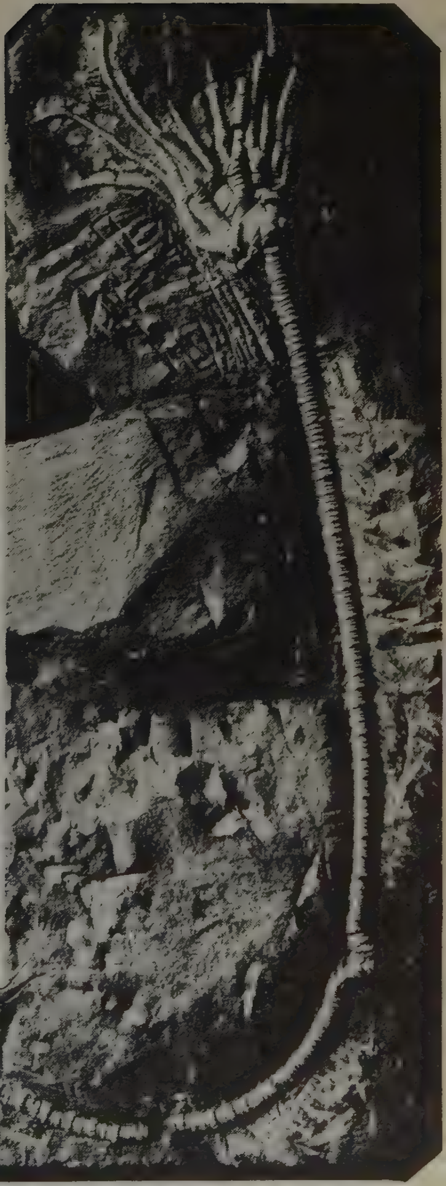
Woodocrinus liddesdalensis sp. nov. from Penton Linns, Liddesdale.



1



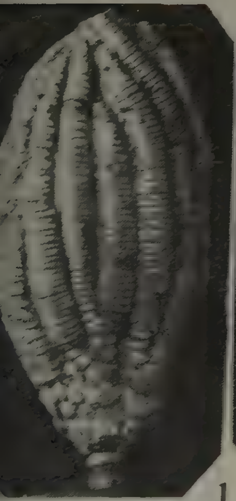
2

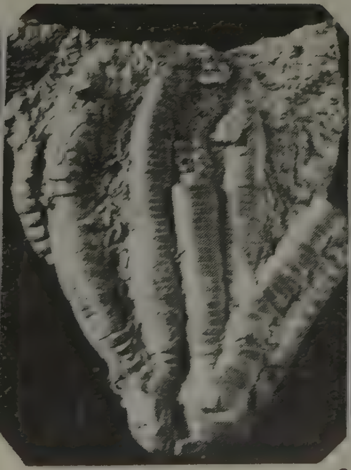


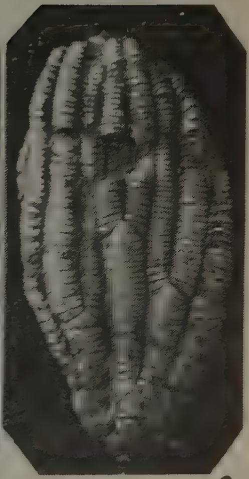
3

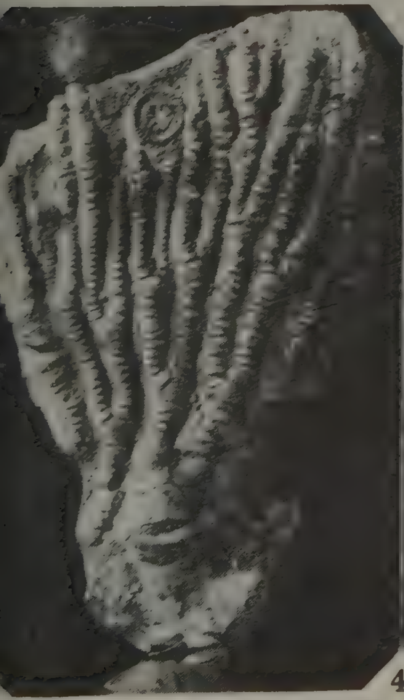
J. Wright Photo.

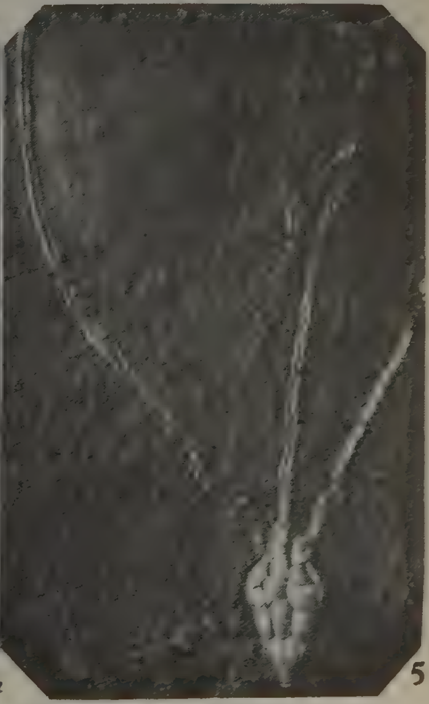
SCOTTISH CRINOIDS.


1


2

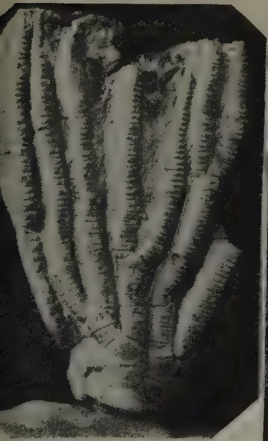

3

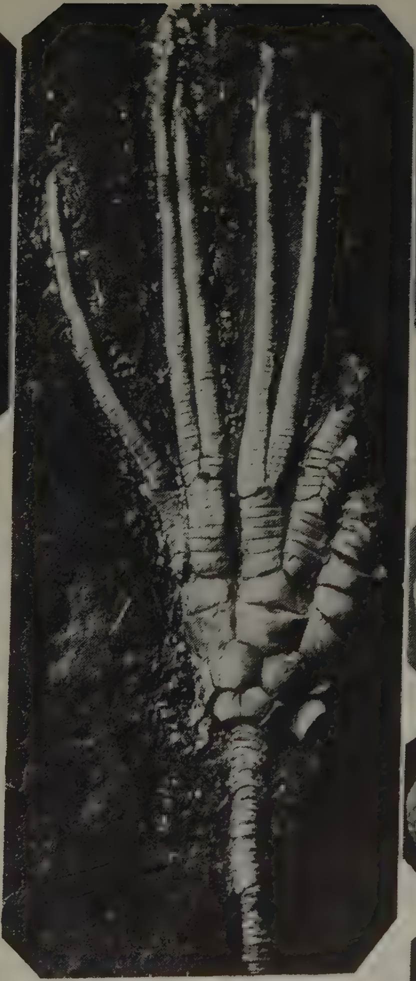

4

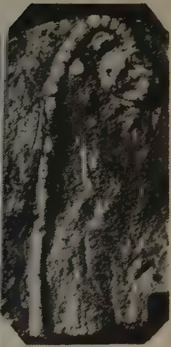

5

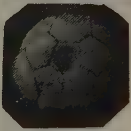
J. Wright Photo.

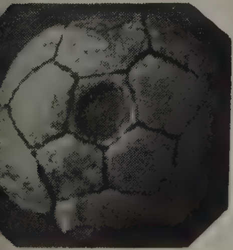
Scottish Crinoids.

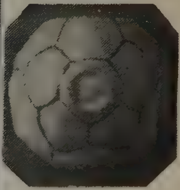

1

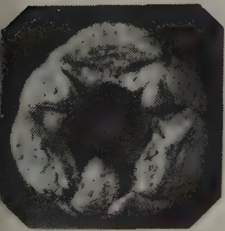

4

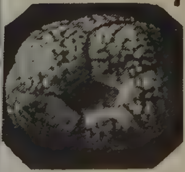

5

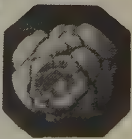

6

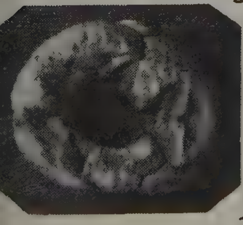

2

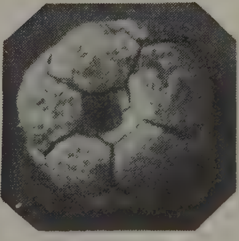

7

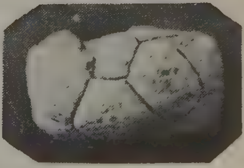

3


8


9


10


11


12

J. Wright Photo.

SCOTTISH CRINOIDS.

that in a few cups the basals are more tumid than in any described species, but these may be individual variations only. On the whole, our cups, and the three small crowns, one of which is shown on Text-figs. 33, 34, 35, seem to agree better with the figures of *M. konincki* than with any others, and the largest cups especially with Fig. 5 of the species on Pl. V in " The Crinoidea Flexibilia ". In this connection, it is interesting to note that although none of our cups have the column, or any part of it, in position we find associated with them in the Seafield Tower limestone, at Carlops and particularly at Invertiel, numbers of spindle-shaped columnals (Text-fig. 41) which have a strong resemblance to the columnals of *M. konincki* as figured by Dr. Springer (op. cit., Pl. V. Figs. 5, 6, 7, 8). The column of *M. forbesianus* is of a very different construction, and consists of short columnals, more or less flush throughout, with no depressions at the sutures ; so that if the spindle-shaped columnals found alongside our cups really formed parts of the columns originally attached to them, as seems not unlikely, it is evident that the species is definitely not *M. forbesianus*. It is, of course, possible that these cups belong to an unknown species altogether, but in the absence of more distinctive evidence it seems preferable at present to link them all with *M. konincki*, despite the fact that this species is only known from the Burlington Limestone of America, a much lower platform than our Scottish beds.

(10) *Mespilocrinus depressus* sp. nov.

Plate X, Figs. 2 and 6 ; Text-figs. 36 and 37.

Diagnosis.—Cup large, shallow bowl or saucer-shaped ; IBB circlet in line with or below level of BB ; post. B filling anal area and extending to level of or beyond line of RR.

Holotype.—J. Wright Collection, No. 2075*a*.

Paratypes.—J. Wright Collection, Nos. 2075*b*, *c*, *d*.

Localities.—Seafield Tower limestone, shore, west of Kirkcaldy ; Zone 33 east of St. Monance.

Horizon.—Lower Limestone Group.

Affinities.—Near to cup of *M. forbesianus* de Kon. and Le Hon., but with flat or much depressed IBB circlet.

Dimensions of Holotype.—Height of cup, 5·8 mm., width across RR at top, 14·6 mm.

Remarks.—Associated with the cups just referred to *M.* cf. *konincki* in the Seafield Tower limestone, in Zone 33, east of St. Monance and at Carlops, are a series, numbering fourteen specimens, which clearly belong to a different species, and one that does not appear to be described. Curiously enough these cups, which have a habitus peculiar to themselves and are easily distinguishable, have not been found at Invertiel. They are in general much larger, shallow or saucer-shaped, and the IBB circlet is quite flat and never rises above the level of the basals. In fact, it is more often sunk below this and in some specimens would be entirely hidden by the proximal columnals if these elements were present. The circlet in all cases is invisible in a side view and this is in contrast to the cups of the previous species, where it is always prominently seen from the side and rises considerably above the line of the basals. (In Text-fig. 37 the cup is slightly tilted to show the connection of post. B with IBB). Usually, too, unlike the previous species, the post. basal extends beyond the rim of the radials and above the limits of the cup. To all these cups I now give the name of *M. depressus.* Unfortunately, none of the specimens shows the arm structure, which may have been different from the other species, and none have been found with the column attached. A question one naturally asks is whether the detached spindle-shaped columnals referred to under the previous species have anything to do with this species. To that there can be no definite answer at present, although from the following evidence one is inclined to think they do not. Firstly, this species has not been found at Invertiel where the spindle-shaped columnals occur abundantly alongside the previous species. Secondly, in the Neilson Collection in the Royal Scottish Museum is a specimen with a good part of the column in position (Pl. X, Fig. 5, Text-fig. 40). I have referred to this specimen before (1925, p. 279). I have again examined and cleaned it further, and although both crown and column are rather weathered it now seems certain that it does not come so near to *M. konincki* as was formerly thought. This is shown particularly by the character of the column. Near the crown, which is hanging over as in other species of *Mesoilocrinus*, the columnals are short and more or less barrel-shaped. Twelve of these are about the same shape and vary little except next the cup where they are rather narrower and wedge-like, conforming to the curve of the column. After the twelfth columnal, however, they begin to lengthen and the remaining columnals are long and cylindrical with nearly parallel sides. They are nowhere spindle-shaped, but have little prominences here and there like broken spines or stumps of cirri. From these characters it is evident that this specimen belongs to an undescribed form, but unfortunately the characters of the crown are difficult if not impossible to define. The brachials are much displaced (in Text-fig. 40 this part is merely diagrammatic) and the cup being slightly squeezed may be deceptive as to shape. On the whole, it seems to be rather shallow and of the shape of *M. depressus.* Only two radials and one basal are seen and the anal area is invisible. The IBB circlet is also hidden from view by the proximal columnals but as far as can be judged it has the appearance of being much depressed; accordingly there seems some reason for thinking that this specimen belongs to *M. depressus.* If this interpretation is correct we at least get a clue to the structure of the column in this species.

III. LIST OF LITERATURE.

AUSTIN, T. and T., 1843–8. *Monograph on Recent and Fossil Crinoidea*, London and Bristol.

BATHER, F. A., 1916–17. "Some British Specimens of *Ulocrinus*," *Trans. Geol. Soc. Glasgow*, xvi, 207.

ETHERIDGE, Jr., R., 1892. "A Monograph of the Permo-Carboniferous Invertebrata of New South Wales," pt. ii, Echinodermata, etc., *Mem. Geol. Surv., N.S.W., Palaeontology*, No. 5, 82–97, pls. xii-xxi (with other references).

GEINITZ, H. B., 1846. *Grundriss der Versteinerungskunde*, Dresden and Leipzig.

GRENFELL, J. G., 1876. "Notes on Carboniferous Encrinites from Clifton and Lancashire," *Proc. Bristol Nat. Soc.*, i, 476.

DE KONINCK, L. G., 1854. "Notice sur un Nouveau genre de crinoides Carbonifère du l'Angleterre" [*Woodocrinus macrodactylus*], *Mem. Acad. Roy. de Belge*, Suppl. 1–8, pl. viii.

—— and LE HON., H., 1854. "Récherches sur les Crinoides du Terrain Carbonifère de la Belgique," *Mem. Acad. Roy. de Belge*, 1–208, pls. i–vii.

—— and WOOD, E., 1857. "On the genus *Woodocrinus*," *Brit. Assoc. Report*, 76–8, and *Geologist*, i, No. 1, 12–15, pls. 1 and 2.

McCOY, F., 1847. [*Tribrachiocrinus*], *Ann. and Mag. Nat. Hist.*, xx, 228.

MILLER, J., 1821. *A Natural History of the Crinoidea*, Bristol.

MILLER, S. A. and GURLEY, W. F. E., 1890. "Descriptions of some New Genera and Species of Echinodermata," *Journ. Cincinn. Soc. Nat. Hist.*, xiii, April, 1–59, pls. 1–10.

—— 1889. *North American Geology and Palaeontology*, Cincinnati.

PHILLIPS, J., 1836. *Illustrations of the Geology of Yorkshire*, pt. ii, London.

ROBERTS, G. E., 1865. "Geological Notes on the Mountain Limestone of England," GEOL. MAG., II, 163.

SPRINGER, F., 1920. "The Crinoidea Flexibilia," *Smithson. Institut. Washington*, pub. 2501.

—— 1926. "Unusual Forms of Fossil Crinoids," *Proc. U.S. Nat. Mus.*, 67, Art. 9.

TRAUTSCHOLD, H., 1879. "Die Kalkbruche von Myatachkowa, Eine Monographie des oberon Bergkalks," *Nouv. Mem. Soc. Nat. Moscou*, xiv. 101–180, pls. xii–xviii,

WACHSMUTH, C. and SPRINGER, F., 1879. "Revision of the Palaecrinoidea," *Proc. Nat. Sci., Philad.*, pt. i, 124.

—— 1886. Ditto., pt. iii, 239 (with many references).

WRIGHT, J., 1911–12. "On the Crinoids from the Lower Carboniferous Limestones of Invertiel, Fife," *Trans. Edinb. Geol. Soc.*, x, 49.

—— 1914. "On the Occurrence of Crinoids in the Lower Carboniferous Limestones of Fife," ibid., x, 148.

—— 1917–18. "Carboniferous Crinoids from Fife, with Notes on some Localities and Provisional Lists of Species," *Trans. Geol. Soc. Glasgow*, xvi, 364.

—— 1924. "A *Woodocrinus* Fauna from the Scottish Border," GEOL. MAG., LXI, 270.

—— 1925. "Notes on the Occurrence of Crinoids in the Lower Carboniferous Limestones of Scotland," *Trans. Edinb. Geol. Soc.*, xi, 275.

—— 1926. "Notes on the Anal Plates of *Eupachycrinus calyx* and *Zeacrinus konincki*," GEOL. MAG., LXIII, 145.

—— 1927. "Some Variations in *Ulocrinus* and *Hydreionocrinus*," ibid., LXIV, 353.

—— 1934. "New Scottish and Irish Fossil Crinoids," ibid., LXXI, 241.

YAKOVLEV, N. "Deux nouveaux genres des Crinoides (Poteriocrinidae) du paleozoique superieur du puys de la Petshora," *Traveaux de Musée Geol. près l'Acad. des Sci. l'Urss*, tome iii.

ZITTEL-EASTMAN, 1913. *Text-Book of Palaeontology*, 2nd edit.

IV. EXPLANATION OF PLATES

Plate VII.

Woodocrinus liddesdalensis sp. nov. from Penton Linns, Liddesdale, about one-third natural size. The specimen on left of slab is the holotype, on the right one of the paratypes. J. Wright, Collection No. 2925.

Plate VIII.

Figs.
1.—*Woodocrinus gravis* sp. nov. from No. 3 Bed, Invertiel, J. Wright, Collection No. 430.
2.—*Pachylocrinus dunlopi* sp. nov. from Penton Linns, Liddesdale. J. Wright, Collection No. 2210.
3.—*Woodocrinus liddesdalensis* sp. nov. from Penton Linns. J. Wright, Collection No. 2195.

Figs. 1 and 2 natural size; Fig. 3 approximately one-third natural size.

Plate IX.

Figs.
1 and 3.—*Woodocrinus gravis* sp. nov. from No. 3 Bed, Invertiel, both sides of the holotype, J. Wright, Collection No. 429.
2.—*Woodocrinus gravis* sp. nov. from Roscobie. J. Wright, Collection No. 1077.
4.—*Pachylocrinus tielensis* sp. nov., from No. 3 Bed, Invertiel, the holotype, J. Wright, Collection No. 2199.
5.—*Ulocrinus doliolus* sp. nov. from the Encrinite Bed, St. Andrews, the holotype, J. Wright, Collection No. 1093.

All natural size.

Plate X.

Figs.
1.—*Woodocrinus gravis* sp. nov. from No. 3 Bed, Invertiel, J. Wright, Collection No. 1084.
2 and 6.—*Mespilocrinus depressus* sp. nov. Two photographs of the holotype from Seafield Tower Limestone, J. Wright, Collection No. 2075*a*.
3, 8, 10, 11, and 12.—*Tribrachiocrinus caledonicus* sp. nov. from Seafield, Kirkcaldy. Fig. 3 is the holotype, J. Wright, Collection No. 2072*a*, the others are paratypes.
4.—*Woodocrinus whytei* sp. nov. from Garpel Water, Muirkirk. Whyte Collection, Geological Department, Aberdeen University.
5.—Crown and column of *Mespilocrinus* sp. from Broadstone, Beith, in Neilson Collection, Royal Scottish Museum.
7.—Cup of *Mespilocrinus* cf. *konincki* Hall, from No. 1 Bed, Invertiel. J. Wright, Collection No. 2279*a*.
9.—Cup of *Woodocrinus gravis* sp. nov. from No. 3 Bed, Invertiel.

Figs. 1, 4, 5, 6, 9, natural size, the others × 2.

The Ballachulish Lag at Callert, Loch Leven.

By Professor E. B. Bailey.

I WISH to correct by 40 feet the position hitherto assigned to the outcrop of the Ballachulish Slide (or Lag as it is safe to call it) in one of its four easily accessible exposures on the shores of Loch Leven. The change does not appreciably affect the mapping as shown on Sheet 53 of the Geological Survey one-inch-to-the-mile map of Scotland, but it is of some importance on the ground. The locality lies on the north shore of Loch Leven, within a few yards of the main road, opposite a small cottage, midway between Callert

House and Callert Cottage. A conspicuous little summerhouse is built on the eastern edge of the quartzite listed below. The dip of all the formations is very steep, so that the breadths of outcrop, measured at right angles to strike, correspond roughly with thicknesses. Details are as follows :—

Exposures from West to East.	*Breadth in Feet.*
Grey impure schistose limestone with broad exposure. It is a continuation of the type outcrop of Ballachulish Limestone, which occurs south of the Loch. A purer division of this limestone series is found elsewhere in contact with Ballachulish Slates, but here it is presumably cut out by movement	—
Black graphitic phyllite, mostly covered by beach. Ballachulish Slates much reduced by movement	120
Intensely-sheared rusty graphitic phyllite with quartzite and quartzose bands—pyrite common. Striped Transition Group of Appin Quartzite Series, much reduced by movement	40
Intensely-sheared white quartzite, with gritty texture very seldom preserved: Quartzite of Appin Quartzite Series marking the centre of the Ballachulish Fold (with summerhouse built upon it)	100
Intensely-sheared rusty interbedded quartzite, quartzose bands and graphitic phyllite—pyrite common. Striped Transition Group of Appin Quartzite Series, much reduced by movement, but retaining more of the quartzitic portion of the group than is found in the western outcrop	40
Ballachulish Lag, very well exposed. It cuts out the greater part of the Striped Appin Group, the whole of the Ballachulish Slates and Limestone, and the greater part of the Leven Schists. A moderate estimate places the total at 2,500 feet. The precise position of the lag on the shore is easy to find, since it is marked by a strong contrast of lithology. Moreover the sea waves, while developing little ridges and hollows along the greatly disturbed bedding of the Striped Appin Group, have left the adjacent Leven Schists with smooth joint faces.	—
Grey non-rusty, very thin-bedded, massive mica-schist, with biotite porphyroblasts, in every way typical of the main part of the Leven Schists	45

The beach exposure is interrupted eastwards by gravel ; but the road shows that only a small thickness of unbanded mica-schist occurs at this locality. There follows a broad outcrop of the Banded Group of the Leven Schist Series, succeeded in normal stratigraphical order by Glencoe Quartzite.

In the preceding remarks mention is made of two somewhat similar banded, or striped, transitional groups, the older, the Banded Group of the Leven Schists, the younger, the Striped Group of the Appin Quartzite. Both have a thickness of the order of 500 feet, where unreduced by shearing. The Leven Banded Group carries subordinate graphitic partings ; but these are very much less abundant than their counterparts in the Appin Striped Group. Originally I made the mistake of assigning the eastern outcrop of Appin Striped Group on the Callert shore to the Banded Levens, and accordingly placed the Ballachulish Slide at the eastern margin of the good quartzite, upon which the summerhouse is built (1916,

p. 43). On subsequent visits I have realized that some few feet at least of Appin Striped Group are present between the summer-house quartzite and the Leven Schists. This year I carefully re-examined the exposures at low tide, and was able to fix the exact position of the slide. No one in future should have any difficulty in following the description given above.

Since many more tourists pass through the district now than in former years, the following landmarks are offered as guides to the three other lochside outcrops of the Ballachulish Lag. It is assumed that the visitor carries with him the Geological Survey Sheet 53.

(1) The type exposure occurs on the southern shore of the loch, close by the road opposite the manse of St. John's Church, between Ballachulish village and ferry. The railway separates the road from the coast section, but gates lead across it at either end of the critical exposures (1916, pp. 47, 48; 1934, pp. 518–520).

(2) The St. John's outcrop is continued and supplemented, on the north side of the loch, opposite Eilean Choinneich. Here the coast lies a few hundred yards from the road, which may be conveniently left at a road-metal quarry in Glencoe Quartzite (1916, p. 43; 1934, p. 518).

(3) Similarly the Callert outcrop is continued, though with less complete exposure, on the southern shore of the loch. The landmark in this case is a roadside boathouse (1916, p. 56; 1934, pp. 520, 521).

REFERENCES.

Bailey, E. B., in "The Geology of Ben Nevis and Glen Coe," *Mem. Geol. Surv.*, 1916.

—— "West Highland Tectonics: Loch Leven to Glen Roy," *Quart. Journ. Geol. Soc.*, xc, 1934, 462.

Spilitic Rocks in New Zealand.

By J. A. Bartrum, Auckland University College, New Zealand.

(PLATE XI.)

PRIOR to a discovery made recently by the writer, of spilitic rocks at Great King Island, the largest member of the Three Kings group of islands, about 26 miles north-west of the north-west extremity of the mainland of New Zealand, such rocks had not previously been found in this latter country. Some account of the types represented at Great King Island may therefore be welcome particularly since Gilluly's (1935) recent comprehensive paper has focused attention on spilites and their associations.

The writer is indebted to Messrs. Gilbert Archey and R. A. Falla of Auckland Memorial Museum, for the privilege of joining a party organized by them to investigate in the yacht *Will Watch* the natural history of many of the outlying islands of northern New Zealand

Dr. J. Henderson, Director of the New Zealand Geological Survey, very kindly arranged for analysis of several of the rocks collected. Thanks are due to him for his courtesy and to Mr. F. T. Seelye of the Dominion Laboratory for the skilful and careful analytical work evidenced in the analyses presented in Table I, and for calculation of the norms of the rocks following the C.I.P.W. method.

Unfortunately heavy ocean swell prevented landings being made at other than one or two sheltered places in the Three Kings group, whilst the coastal cliffs can rarely be scaled, so that the field relationships of the spilitic series of rocks encountered could not be established with certainty. It is particularly regrettable that circumstances did not permit collection from a series of columnar igneous rocks outcropping on some of the western islets of the group.

The types of igneous rocks collected from Great King Island are as follows:—

(*a*) Quartz-keratophyre.
(*b*) Albitic porphyry.
(*c*) Spilitic pillow lava.

The basement rock of Great King Island is mainly greywacke the precise age of which is unknown, but which is referable with some degree of confidence to the Hokonui System of greywackes and allied sediments; these are approximately mid-Mesozoic in age and are widespread throughout New Zealand, constituting its main axial ranges. Near where the igneous rocks were located at Great King Island the greywacke is associated with black argillite and a little quartz conglomerate.

The pillow lava outcrops near sea-level in a band about 40 feet thick interbedded with greywacke and traceable in the sea-cliffs for about 200 yards. The pillow form is seldom conspicuous and, in the field, the lava at times was separable with difficulty from the greywacke associated with it, for both have a fine-grained, even texture and are similarly crossed by close-spaced intersecting joints. Irregular veins of calcite, sometimes as much as 2 feet thick, are not infrequent in the igneous rock.

The porphyry forms a flat-lying sheet about 60 feet in thickness, so far as could be determined, which outcrops high in the sea-cliffs, though masked over much of its accessible portion by talus. Locally it is much broken by joints, probably on account of shear zones, which are well exhibited near at hand, though at other places it is not, for unjointed blocks which may be as much as 40 feet in diameter litter the shore below the outcrop. The texture of the rock indicates that it is almost certainly intrusive and, as its attitude shows approximate conformity with that of the pillow lavas, which are not far distant but at a much lower level, it would appear that the intrusion is a sill.

The acidic rock recorded was collected from surface blocks near the castaways' depot, which is within about 150 yards of where the porphyry outcrops in the sea-cliffs, but about 200 feet above this outcrop. Its composition is that of a quartz-keratophyre, but there is some doubt as to whether the rock is actually a lava, for thin sections of some of the blocks show many tuffaceous characters. Nevertheless certain features which are dealt with below incline the writer to the belief that most of the blocks represent an effusive rock.

DETAILED PETROGRAPHY.

(*a*) *Quartz-Keratophyre* (see Analysis 1, Table I).

As just noted, thin sections leave room for doubt as to whether this rock was wholly tuffaceous or was also outpoured as a lava. The typical section shows widely separated, somewhat infrequent, stout phenocrysts of clear albite, up to 1·8 mm. in greatest dimension, which sometimes have idiomorphic but at other times ragged outlines. Twinning by the albite law is general. The matrix constitutes over 90 per cent of the rock and is an intimate mixture mainly of minute grains of quartz and felspar, this latter with an ill-defined tendency towards rectangular form. In addition there are occasional small grains of epidote and numerous tiny shreds of chlorite sometimes grouped in lines suggestive of flow lines, for they curve around the phenocrysts. Analysis shows that the felspar of the groundmass is dominantly albite. Iron ore is absent, though occasional small irregular grains of sphene are probably derived from ilmenite. There are a few replacements by chlorite, quartz, and felspar of an earlier mineral, the flakes of chlorite being grouped along lines which suggest original cleavage planes; conceivably this replaced mineral was a lime-soda felspar.

Evidence in favour of regarding this quartz-keratophyre as a tuff is afforded by one thin slice which, though indistinguishable under crossed Nicols from other slices of the rock, under ordinary light is seen to consist of small fragments and pellets, each outlined more or less prominently by shreds of chlorite. On the other hand, features of other thin sections suggest that the rock was also effusive in its occurrence. For example, as already mentioned, the disposition of flakes of chlorite points to fluxional control; the flow lines, if they are such, are not continuous, however, whilst those of one area may be far from parallel to those of the next. In addition the euhedral form of many of the phenocrysts of albite and their not infrequent occurrence in groups of interpenetrating members (Pl. XI, Fig. 1) suggest that the parent material was not subjected to such intense explosive activity as the fine state of subdivision (0·02 mm.) of the matrix would demand were this latter tuffaceous.

The writer is strongly inclined to believe, therefore, that flow rocks as well as tuff are represented in the blocks of quartz-keratophyre; it appears, however, that the lavas must have reached the surface in viscous condition or the flow structure faintly demonstrated would have been more evident and regular in its disposition.

The view that lava is represented is substantiated by the fact that, in the tuffaceous type sectioned, the individual rounded pellets are identical in constitution and texture with the matrix of the phase believed to be effusive. In addition, similar texture is occasionally to be seen in rocks which are clearly lavas, as, for example, in a few of the comendites of Mayor Island, New Zealand.

TABLE I.

ANALYSES OF SPILITIC ROCKS.

	1	2	3	4	5
SiO_2	75·10	63·58	52·94	53·15	51·22
Al_2O_3	12·84	13·42	12·81	14·39	13·66
Fe_2O_3	0·70	2·10	3·76	1·28	2·84
FeO	1·36	5·67	9·29	9·33	9·20
MgO	0·30	1·37	3·65	4·74	4·55
CaO	0·32	2·75	6·22	7·04	6·89
Na_2O	5·12	4·31	5·25	4·58	4·93
K_2O	2·39	2·93	0·18	1·01	0·75
H_2O-	0·27	0·30	0·21	0·19	—
H_2O+	0·95	1·85	2·33	2·02	1·88
CO_2	0·03	0·03	none	0·10	0·94
TiO_2	0·22	0·99	2·54	1·50	3·32
ZrO_2	0·01	0·01	none	—	—
P_2O_5	0·04	0·35	0·36	0·19	0·29
S	0·06	0·02	0·12	—	—
Cl*	0·02	trace	0·02	—	—
Cr_2O_3	none	none	none	—	—
MnO	0·04	0·14	0·21	0·14	0·25
NiO	none	0·01	0·02	—	—
BaO	0·05	0·05	trace	none	—
SrO	trace	0·01	none	—	—
	99·82	99·89	99·91	99·66	100·72

* The chlorine is almost certainly due to sea-spray.

1. Quartz-keratophyre, Great King Island, Three Kings Islands, north-west New Zealand. F. T. Seelye analyst.
2. Albitic porphyry, Great King Island, New Zealand. F. T. Seelye analyst.
3. Spilite, Great King Island, New Zealand. F. T. Seelye analyst.
4. Spilite: N.E. ¼, sec. 35, T. 7 S., R. 42 E., Oregon. Quoted from Gilluly (1935, p. 235). J. G. Fairchild, analyst.
5. Average spilite. Computed by N. Sundius (1930).

(*b*) *Albitic Porphyry* (Analysis 2, Table I).

As has been stated above, the writer believes that this rock constitutes a sill about 60 feet thick, intruded into greywacke and black argillite, which constitute the basement rock of the area. All specimens collected came from blocks fallen from an outcrop about 300 feet higher in the sea-cliffs, for these were less weathered than the outcrop material and afforded greater variety, since accessible parts of the outcrop are largely obscured by talus. In the short time available it was impossible to locate the contacts between the sediments and the igneous rock with precision, for, on approaching the sediments, the porphyry becomes finer in grain and practically indistinguishable macroscopically from adjacent greywacke.

The fallen blocks exhibit definite variation in grain size and texture. All show considerable development of secondary minerals such as chlorite, epidote, calcite, and quartz, generally, with the exception of chlorite, in amygdules and nests, though epidote and sometimes opal may form a lining to joint crevices. Nests of calcite as much as 4 inches in diameter were noted, as well as concentrations of deep yellowish-green epidote, attaining a thickness of as much as 8 inches over an extent of several square feet. Though in places strongly amygdaloidal, the rock generally is not so.

The specimen selected for analysis represents a finer-grained facies, and, though much less altered than other types sectioned, contains nevertheless an important proportion of chlorite, though epidote, which is abundant in the coarser phases, is in insignificant quantity. Radiating secondary calcite is in small amount.

TABLE II.

C.I.P.W. NORMS OF SPILITIC ROCKS FROM NEW ZEALAND.

	1	2	3
Q.	34·28	17·65	3·12
Or.	14·14	17·31	1·06
Ab.	43·31	36·44	44·41
An.	1·59	8·65	10·88
C.	1·25	—	—
Di.	—	2·27	14·68
Hy.	2·43	9·56	12·04
Mt.	0·91	3·06	5·26
Il.	0·43	1·88	4·83
Ap.	—	0·84	—
Pr.	0·12	—	0·23

SYMBOLS: I. (3) 4.1.4, Kallerudose; ″ II.4.2.4, Dacose; (II) III.5.2.5. Kilauose.

This rock contains somewhat rare, lath-shaped phenocrysts of albite up to 1·8 mm. in length, which are surrounded by a felted matrix mainly composed of unoriented laths of felspar about 0·2 mm. in length; these enwrap about 10 per cent of colourless to pale-green diopsidic augite in stumpy crystals, whilst there is a noteworthy residuum of quartz. The augite is largely converted to chlorite which has been widely dispersed, tiny granules frequently appearing in the felspar. Orthoclase was detected here and there, but not in the considerable percentage indicated by the analysis. Conceivably it is partly in solid solution in the albite, as is suggested by Gilluly (loc. cit., pp. 228–9).

Exact determination of the felspars proved difficult. Refractive index tests and extinction angles show that the phenocrysts and several of the larger laths of the groundmass are close to pure albite. On account of the dispersed chlorite, however, the refractive index of the smaller laths general in the matrix could seldom be obtained; it was established, however, that oligoclase is present, though its proportions relative to albite and its exact composition are unknown. The norm (No. 2, Table II) suggests that oligoclase of moderately calcic nature is the dominant felspar, but it is unknown to what extent lime and alumina calculated as anorthite in the norm are actually present in the pyroxene.

In one of the thin sections examined, the felspar enwraps the pyroxene ophitically, whilst quartz in turn micropoecilitically encloses the laths of felspar, so that the texture contrasts strongly with that of other sections. If recognizable quartz were not even more abundant than in other phases of the rock, one would be tempted to class this ophitic type as an albitic quartz-diabase comparable with the diabases common in other spilite associations. Again, one coarse-grained strongly altered type, in which secondary epidote in particular is prominent in the large concentrations already noted, possesses relatively little recognizable quartz, and may well represent a more basic phase of the intrusion. The epidote is deep yellow in section and is plentifully associated with chlorite in various stages of replacement of augite; it is also abundant as the filling of vesicles or other spaces. The evidence appears to point clearly to the conclusion that its lime has not been obtained by decalcification of lime-soda felspar.

The variation in type that is made evident by sections conforms with that noted at the outcrop of the intrusive mass represented by the fallen blocks sectioned. In the absence of sufficient information, it is useless making speculations as to whether the parent mass shows some degree of internal banded differentiation or consists of a series of injections of different composition, though such observations as are available are against this latter possibility.

(c) *Spilitic Pillow Lava* (Analysis 2, Table I).

Although it possesses a percentage of silica which places it just within the commonly accepted limits of the intermediate class, this rock has proportions of normative plagioclase to femic minerals which classify it as a basalt, following the terminology of Washington (1923). The rock is a fine-grained holocrystalline type, consisting essentially of a more or less felted mass of laths of felspar interwoven with grains or long, narrow prisms of pale-brown augite sometimes as much as 1·5 mm. in length; the prisms of augite and the laths of felspar not infrequently are strongly bent (Pl. XI, Fig. 2). Iron ore occurs in tiny crystals; ilmenite and magnetite both are present, though their percentage would appear to be much less than the norm (No. 3, Table II) would indicate.

The only crystals that may be considered phenocrysts are occasional laths of albite decidedly larger than those of the general mass. Even here, however, the felspar laths are of two sizes, for in the mesh of a general fabric of coarser nature there is a residuum of very finely crystalline material in which the microlites of felspar are very minute. There is a well-marked tendency for the minerals to occur in rosettes or other divergent growths (Pl. XI, Fig. 3).

The felspar is somewhat in excess of the pyroxene. Its determination proved unsatisfactory, particularly in so far as the relative proportions of albite and oligoclase are concerned. Both are present; the albite, however, was determined only in the larger phenocrystic laths, whilst its occurrence in the more general ones of smaller size is somewhat doubtful. Oligoclase almost certainly is the main felspar; the norm of the rock (No. 3, Table II) indicates that its composition is $Ab_{81}An_{19}$, but it probably actually is much more sodic, since the pyroxene is an aluminous variety.

Almost all of the pyroxene is a slightly titaniferous variety of augite, which shows occasional faint pleochroism in violet brown tints. There is, however, also what appears to be a second pyroxene of different and, if actually a pyroxene, interesting character. This is a strongly pleochroic mineral with tints ranging from a deep bluish-green to pale brownish-violet; one crystal, which is present in a veinlet along with others showing the usual pleochroic tints, shows change from a deep grass-green to a golden yellow colour. The refractive index of the mineral is close to that of augite, whilst its cleavage is well marked, though only in the one direction in the few somewhat larger crystals available in the thin sections cut (Pl. XI, Fig. 4). Extinction angles obtained with the cleavage agreed with those for augite, whilst unsatisfactory interference figures indicate that the optic axial angle is large and the optic character probably positive. This pleochroic mineral occurs in small quantity in narrow quartzose veins of more coarsely crystalline nature than the general rock, as well as in rare, tiny crystals scattered throughout this latter. Its outlines are invariably irregular, for it is clearly a late product of crystallization. Its occurrence in narrow veinlets of relatively coarse nature indicates that it probably has crystallized from a liquid enriched in volatile constituents, so that it is regrettable that its exact identification has been found impracticable with the limited resources of the writer.[1] It may be mentioned that injections of very finely crystallized lava appear as narrow, definite veinlets in addition to the quartzose ones that contain this pyroxene-like mineral.

The only important secondary minerals present in the rock are about 10 per cent of chlorite along with amygdaloidal quartz and some calcite; this last mineral occupies various crevices and may locally form lensoid, discontinuous veins as much as 2 feet in width. The chlorite is prominent in small aggregates about 0·2 mm. in diameter as well as dispersed in the minute interstices of the matrix; there is no sign of its derivation from the augite.

---

[1] Since this was written the thin sections have been examined by Dr. N. L. Bowen, who suggests that the mineral concerned is one of the epidote group.

In spite of the fact that the pillow lava described herein apparently has oligoclase as its dominant felspar, its analysis is closely comparable with that given by Sundius (1930) as representing the average spilite (see Analysis 5, Table I), and approaches even closer to that of a spilite described from Oregon by Gilluly (loc. cit., p. 235), which is reproduced in Analysis 4 of Table II. The Great King rock is thus to be classed as a true spilite. Its occurrence in pillows interbedded with greywackes for which a marine origin is confidently accepted by New Zealand geologists demonstrates that it was poured out on the floor of the sea, for coarser clastic beds might have been expected between the lava and the enclosing greywacke had recession of the sea preceded its emission.

CONCLUSION.

The association at Three Kings Island of ellipsoidal spilite associated with quartz-keratophyre and intermediate intrusive rock is well in accord with the known facts of the occurrence of spilites. Gilluly (1935) has recently summarized these facts and has so ably discussed the origin of the rocks that it is unprofitable to add further discussion. It will suffice to state that, in the writer's opinion, there is no cogent reason for regarding both the albite and the oligoclase of the Three Kings spilitic rocks as other than primary in the fullest sense. This is in opposition to the conclusion at which Gilluly arrived after study of his Oregon rocks, and a full survey of the literature of spilites, for, whilst believing that oligoclase present is probably primary, he concludes that the albite has been crystallized from soda-rich solutions which have effected metasomatic enrichment in albite of earlier normal rocks subsequent to their consolidation. It is true that the albitic porphyry described by the present writer locally shows ophitic structure, which is relied on by Gilluly as evidence of metasomatic replacement, but there is, however, no trace in the New Zealand rocks of mottling of the felspars, such as is described by this latter writer (Gilluly, loc. cit.). The chlorite and epidote present in the porphyry, especially in its coarser phases, are frequently abundant in altered rocks that are not enriched in the albite molecule, and cannot, therefore, be taken as evidence of the passage of solutions of sodic character. It is indeed difficult to imagine how such solutions could have traversed such a fine-grained rock as the Three Kings spilite and have left no trace of their passage apart from the deposition of chlorite and the possible albitization of original felspars. If there had been any important uprise of soda-rich fluids, alteration of the greywackes associated with the igneous rocks at Great King Island could confidently be expected, for these sediments approach granodiorites in mineralogical composition. Field inspection gave no hint of such alteration; the rocks concerned have not, however, been examined microscopically, for the albitic nature of the igneous rocks collected was not suspected until they were sectioned.

Little unfortunately is yet known of other igneous associates of the spilitic types discovered, for, as already mentioned, the writer did not have the opportunity of collecting from columnar rocks of basaltic type which outcrop in islets west of Great King Islands.

Pillow lavas of normal basaltic type and approximately Upper Cretaceous in age occur with sheet lavas of similar composition, which are thought to be of about the same age as the pillow lavas, near Cape Maria van Diemen at the north-west extremity of the mainland of New Zealand (Bartrum and Turner, 1928; Bartrum, 1934). They cannot be regarded as the magmatic associates of the Three Kings rocks, for these latter are older: their period of eruption is separated from that of the lavas of the mainland by one of the greatest unconformities yet established in New Zealand. It would be of interest, however, to re-examine the basaltic rocks which Bell and Clarke (1909) record as forming thick sheets interbedded with Mesozoic greywackes in the Whangaroa Subdivision about 60 miles south-east of the lavas near Cape Maria van Diemen, for these greywackes without doubt belong to the same series as those at Great King Island. Spilites may well be found amongst the Whangaroa basalts.

In conclusion it may be stated that no attempt can reasonably be made, without further knowledge of the field relationships and associations of the rocks described in this paper than is at present available, to discuss any bearing that they may have upon the vexed questions of the genesis of spilites and the existence or otherwise of a spilitic suite. Even the order of succession of the three spilitic rocks discovered is uncertain, though the pillow lava seems to have appeared before the other two types.

This paper aims, therefore, at little more than recording for the first time the occurrence in New Zealand of a spilitic series of rocks associated with sediments approximately mid-Mesozoic in age. This discovery throws an interesting sidelight upon the presence of soda-granite, keratophyre, and other albitic rocks as pebbles in Jurassic conglomerates at Kawhia on the west coast of the southern portion of Auckland Province (Bartrum, 1935).

Microscopic examination of the three members of the spilitic association discovered at Three Kings Islands appears to suggest that the felspars of the rocks may well be primary crystallization products of magmatic fractions enriched in albite molecules.

LITERATURE REFERRED TO.

Bartrum, J. A., 1934. "The Pillow-lavas and Associated Rocks of North Cape Area, New Zealand," *N.Z. Journ. Sci. and Techn.*, xvi, 158–9.

—— 1935. "Metamorphic Rocks and Albite-rich Igneous Rocks from Jurassic Conglomerates at Kawhia," *Trans. Roy. Soc. N.Z.*, lxv, 95–107.

—— and Turner, F. J., 1928. "Pillow-lavas, Peridotites and Associated Rocks of Northermost New Zealand," *Trans. N.Z. Inst.*, lix, 98–138.

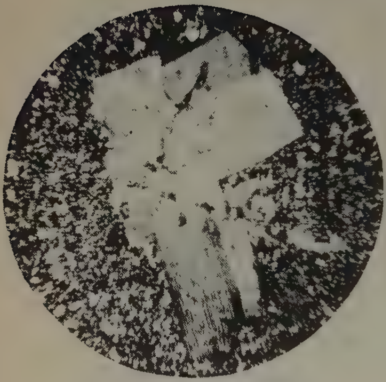


FIG. 1. ALBITE IN QUARTZ-KERATOPHYRE.

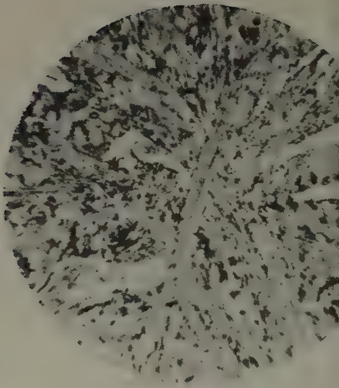


FIG. 2. SPILITE LAVA.

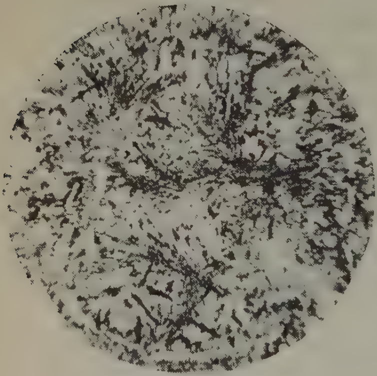


FIG. 3. SPILITE LAVA.

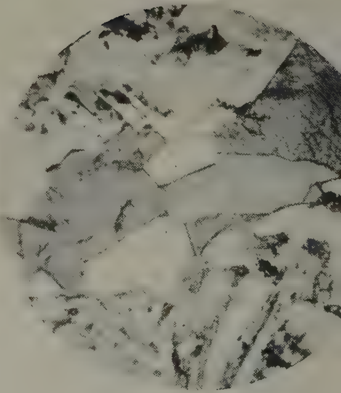


FIG. 4. UNKNOWN MINERAL IN SPILITE.

Bell, J. M., and Clarke, E. de C., 1909. "The Geology of the Whangaroa Subdivision," *N.Z. Geol. Surv. Bull.*, No. 8 (n.s.).
Gilluly, J., 1935. "Keratophyres of Eastern Oregon and the Spilite Problem," *Amer. Journ. Sci.*, ser. 5, xxix, 225–252 and 336–352.
Sundius, N., 1930. "On the Spilitic Rocks," Geol. Mag., lxvii, 1–17.
Washington, H. S., 1923. "Petrology of the Hawaiian Islands: I. Kohala and Mauna Kea, Hawaii," *Amer. Journ. Sci.*, ser. 5, v, 465–502.

EXPLANATION OF PLATE XI.

Fig.

1.—Albite in quartz-keratophyre, Great King Island, New Zealand. Nicols crossed. Magnification, 23 diams.

2.—Photomicrograph of spilite, Great King Island, New Zealand. A long, curved prism of augite is prominent; grey aggregates of chlorite can be separated from the pyroxene by their equant form and lesser relief. Magnification, 36 diams.

3.—Photomicrograph of spilite, Great King Island, New Zealand, showing typical divergent growths of constituent minerals. Magnification, 23 diams.

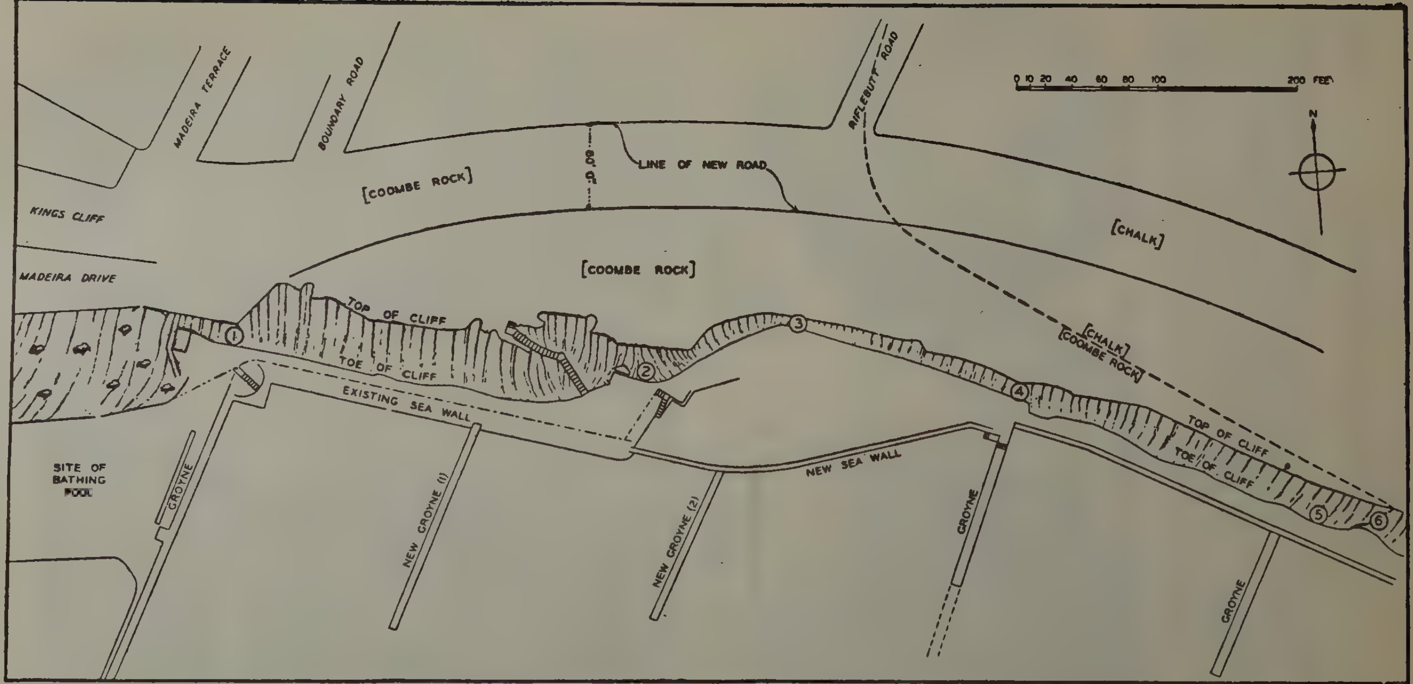
4.—Pleochroic undetermined mineral (? a pyroxene) in narrow felspathic veinlets penetrating the spilite of Great King Island, New Zealand. Magnification, 140 diams.

Levels in the Raised Beach, Black Rock, Brighton.

By the late Dr. Bernard Smith.

In 1932, during the early stages of the construction of the undercliff sea wall between Brighton and Rottingdean, whereby the foot of the cliff has now been protected from marine erosion and its top from undue recession in future, opportunity was taken to examine the sections of Coombe Rock and Raised Beach exposed at Black Rock. The face of the cliff has been trimmed and sloped back here and there in the interests of promenaders beneath and, what with this and a certain amount of walling-up, the sections are now less clear and extensive than they were in the first stage of the work. At several points, however, the Raised Beach overlain by the Coombe Rock ("Elephant Bed") is (April, 1936) well exposed, and its top and/or bottom may still be examined.

Since the foot of the modern cliff is now "tied down", the observed levels of the raised beach will not be likely to suffer much change in future. Figures indicating levels of the beach that may have been published from time to time in the past have shown differences for two reasons: (1) The beach at its eastern end is at high level close up against the foot of the old chalk cliff that is buried beneath the Coombe Rock, whereas at its western end it is a considerable distance from the old cliff and consequently lies at a lower level. Thus, when only one level has been given, that particular level would refer solely to the point in the beach at which the observer took his measurements; (2) Before the new wall was built the cliffs had been receding at a rate of approximately 1 yard



TEXT-FIG. 1.—Plan of Cliffs at Black Rock, Brighton, showing points at which levels in the Raised Beach have been taken. The encircled numbers mark the sites at which measurements of the top and base of the Raised Beach were made.

(*Published by permission of the Borough Engineer.*)

per annum (it has actually receded 30 yards in thirty years); hence at most points the exposed portion of the raised beach, as it has been weathered back with the rest of the modern cliff, has been getting progressively higher and higher above sea level, as it has gradually approached the buried cliff on the rising beach platform.

It seemed advisable, therefore, to take levels at several points along the whole line of the exposed beach, so that the relative values of these levels would be apparent and there would be no ambiguity.

The Borough Engineer and Surveyor of Brighton, Mr. David Edwards, M.Inst.C.E., F.S.I., who is responsible for the design and success of the works, on the suggestion of the writer, instructed a member of his staff to take levels, relative to the Liverpool Datum (O.D. Mean Tide Level), of the top and bottom of the beach and of the modern cliff top, at six selected points along the exposed front of the beach. These measurements, recorded in feet, are given below by kind permission of the Borough Engineer, the six points being shown in the accompanying plan, Fig. 1.

Site.	*Top of Raised Beach.*	*Base of Raised Beach.*	*Thickness.*	*Top of cliff.*
1	26·5	?	?	76·5
2	29·0	below 24·5	+ 4·5	80·0
3	35·0	,, 23·5	11·5	79·0
4	33·0	26·5	6·5	96·0
5	38·0	26·5	11·5	102·0
6	35·5	29·5	6·0	105·5

It would appear from the measurements that the surface of the beach rises from 26·5 feet at site **1** to 35 feet at **3**, and then falls to 33 feet at **4**, rises to 38 feet at **5**, and finally drops again to 35·5 feet.

The fall between **3** and **4**, however, is fictitious, for about 15 yards west of **4** strings of beach-pebbles continuous with the top of the beach at **3** tail out eastward—3 feet (plus or minus) above the top of the main deposit—in a rough accumulation of chalk blocks and rubble that had fallen on the beach from the buried cliff. On this evidence we may take it that the raised beach itself was really about 10 (if not 11) feet thick, though its top here is replaced by fallen rubble. Hence at **4** we may raise the figure for the level of the beach top from 33 to about 36·5 feet.

At site **6** one comes to the point where the raised beach actually touches the old cliff face, which here emerges obliquely from beneath its swathing of Coombe rock, and for a short distance coincides with the modern cliff. All that is left is a few feet of pebbles clinging to the cliff face, so that the true height of the top cannot be judged accurately—it must have been at least as high as, if not a foot or so higher than at **5**, a few yards away, where the whole thickness is visible. Similarly the true base of the raised beach is no longer visible at **6**.

Thus the levels and thickness of the beach may be restated as follows:—

Site.	*Top of Raised Beach.*	*Base of Raised Beach.*	*Thickness.*	*Top of cliff.*
1	26·5	?	?	76·5
2	29·0	below 24·5	4·5 +	80·0
3	35·0	about 23·5	11·5	79·0
4	36·5 +	26·5	10·0 +	96·0
5	38·0	26·5	11·5	102·0
6	? 39·0	below 29·5	9·5 +	105·5

Mr. Osborne White has given a full account of the Brighton Raised Beach as it appeared about twelve years ago, and to this readers may be confidently referred.[1] A few remarks on the different localities will not, however, be out of place.

Site **1**.—The beach is no longer visible here, having recently been walled-up to provide a sloping walk behind the new Bathing Pool buildings.

Site **2**.—The top inch or so of the beach here is sandy, and contains marine shells. Viewed from the new sea wall, near New Groyne (2), the beach in the angle where the cliff swings inland a few yards east of **2** may be seen to be false-bedded, the bedding tilting seaward. The top is overlain unconformably by the Coombe Rock, which is inclined seaward at a less steep angle. The beach here contains only small fragments of chalk.

Site **3**.—Here a very fine section of the beach is exposed; probably its full thickness, since the chalk floor appears a few yards farther east and rises gently in the cliff face (still unwalled) to positions measured at sites **4** and **5**. The beach at **3** contains only a few large blocks of chalk.

About 13 yards east of **3** large chalk blocks and chalk rubble form an increasing proportion of the beach, as compared with pebbles.

Sites **4** and **5**.—Large blocks of chalk up to 2–3 feet in size are especially noticeable between **4** and **5**, where the bottom of the beach is now walled up. Similar large blocks occur in the overlying Coombe Rock.

It is clear that the raised beach section east of Site **3** where it is full of large fallen blocks of chalk is fairly close to the old buried cliff. This is borne out by observations made when the new road was constructed along the top of the present cliff at the same date as the works (1932). The boundary of the Coombe Rock was traced by the writer in the surface cutting then made. This line is shown on the plan (Fig. 1), and it will be seen how the swing inland of the buried cliff is reflected in the absence of large fallen blocks of chalk in the beach at sites **1**, **2**, and **3**. They set in, however, and occur in increasing numbers east of site **3** up to the point where the beach touches the old cliff.

---

[1] The Geology of the Country near Brighton and Worthing, *Mem. Geol. Survey*, 1924, 73–6 and pl. iv.

REVIEWS.

Road Aggregates: their Uses and Testing. By B. H. Knight. The Roadmakers' Library, vol. iii. pp. x + 264, with 112 text-figs. London: Edward Arnold and Co., 1935. Price 21*s.*

THE art and practice of road-making in this country are in advance of fundamental knowledge of what in the raw materials constitutes strength and gives endurance to the finished road construction. In volume iii of Arnold's Roadmakers' Library, we have a convenient compilation of available information by an engineer who knows the value of the petrographic method and has recognized that flaws and cracks observed under the microscope in the body of the stone tell more of the probable behaviour of the material in service under traffic than can be ascertained by any standardized abrasive or percussion tests.

Catalogue of Types and Figured Specimens of Fossils in the Geological Survey Collections, exhibited in the Royal Scottish Museum, Edinburgh. By E. M. Anderson. pp. 1–77. Department of Scientific and Industrial Research, H.M. Stationery Office, 1936. Price 1*s.* 6*d.*

THE type and figured material from Scottish localities belonging to the Geological Survey is exhibited in a gallery of the Royal Scottish Museum, though under the charge of the Assistant Director of the Geological Survey. The present catalogue of this is a useful compilation, on the publication of which the Survey is to be congratulated. The arrangement is primarily stratigraphical and as might be anticipated, the bulk of the material is of Carboniferous age. Within each system, the arrangement is zoological, and a given specimen can be run down easily, though the addition of an index might have been an advantage.

Practical Photo-Micrography. By J. E. Barnard and F. V. Welch. 3rd edition. pp. xii + 352, with 23 plates and 119 text-figures. London: Edward Arnold and Co., 1936. Price 21*s.*

PHOTOGRAPHY naturally plays an important part in petrology and mineralogy, as in nearly all modern sciences, and among its many applications are what everybody in real life always calls micro-photographs, in spite of the pedantry of editors and their photo-micrographs. However, in the photography of mineral sections and rock-slices many of the greater difficulties do not arise, as the magnification is usually what a biologist would consider quite low, rarely exceeding one hundred diameters. What the petrological photographer really wants is a very steady and therefore heavy apparatus; a large, strong, and even source of light, and a microscope really effectively blacked inside. On the first two of these points many useful tips may be obtained from this book, which is written by two well-known experts and gives a very clear description of the construction, adjustment, and use of many types of apparatus for micro-photography of all kinds. There is little or nothing about the use of polarized light, which greatly increases the difficulties to be overcome by the photographer. It may, however, be safely said that for nearly all purposes photographs taken with crossed nicols are practically useless, and especially for reproduction. For illustration of rock-sections no photograph can equal the beautiful line-drawings of Dr. Harker or the late Dr. H. H. Thomas.

R. H. R.

GEOLOGIE VON EUROPA, Band 2, Teil 3. By SERGE VON BUBNOFF. pp. v, 1135–1602, 1 table, 104 text-figures. Berlin: Borntraeger.

THE closing volume (called "part") of this monumental work is divided into two distinct sections. The first and much the larger section (289 pages) is an admirable and highly informative résumé of what is known up to the present of the general form, structure, and tectonics of the Mesozoic and Tertiary tracts of extra-Alpine Europe, with special reference to the original distribution and evolution of the troughs and basins of deposition. To each chapter is appended a summary of the ores, coal, oil, salt, etc., found in the area. This part of the book is therefore rather a "Summary and Conclusions" belonging to Part 2 (reviewed in the June number of this Magazine, p. 280). No other account of the subject has anything approaching the comprehensiveness of scope or wealth of critically-handled detail, arranged with masterly breadth of outlook, that characterize this work.

The second and smaller section of the book (64 pages) is devoted to the stratigraphy and general aspects of the Quaternary rocks, with a folding correlation table and a bibliography of over 200 items (nearly all in German). There follow supplements and corrections to earlier parts, and nearly 100 pages of indexes to the whole of volume 2.

Professor von Bubnoff deserves the gratitude and congratulations of all geologists for the completion, in the quiet isolation of Greifswald, of a truly noble contribution to the science. It will be an indispensable reference work, and one which differs from many of the class by tempting the reader to prolonged explorations.

W. J. A.

MINERALOGY: AN INTRODUCTION TO THE STUDY OF MINERALS AND CRYSTALS. By E. H. KRAUS, W. F. HUNT, and L. S. RAMSDELL. 3rd edition, pp. 368, with 812 text-figures. McGraw-Hill Publishing Co., Ltd., London and New York, 1936. Price 30*s*.

IN this, the third edition of this useful work, Professor L. S. Ramsdell, also of the University of Michigan, is associated with the two original authors, and the book has been increased in size by over thirty pages and sixty-six new illustrations; among these we note with pleasure a portrait of Dr. L. J. Spencer. It may be noted that W. H. Miller was Professor of Mineralogy at Cambridge from 1832 to 1880, not 1870, as stated in the caption of his portrait on p. 17. Numerous additions have been made to various chapters, especially those dealing with the more recent developments of crystal-structure and its X-ray analysis, as well as in optics and mineral-formation. In the descriptive sections many interesting details, often accompanied by illuminating photographs, are given of the exploitation and practical uses of minerals, such as are likely to prove stimulating to students who are inclined to regard the subject of mineralogy as commonly taught as wholly transcendental and of little or no technical importance.

R. H. R.

INDEX TO THE RECORDS OF THE GEOLOGICAL SURVEY OF INDIA. Vols. I–LXV, 1868–1932. By T. H. D. LA TOUCHE. pp. viii + 718. Calcutta: Geological Survey of India, 1936. Price 11*s*.

AFTER thirty years work in India and Burma on the Geological Survey of India, Mr. La Touche has devoted his leisure to the very useful and laborious task of indexing the literature of Indian Geology. He has compiled a bibliography and a series of indexes which for thoroughness and completeness are without parallel elsewhere. It is in fact now much easier to find what has been written upon any subject connected with the geology of India and the neighbouring regions than it is for any other part of the world.

The volume before us is the seventh that he has issued, all of them published by the Government of India and sold at the office of the Geological Survey of India. The first was *A Bibliography of Indian Geology and Physical Geography*, Part IA, which appeared in 1917. This was followed by Part IB,[1] *An Annotated Index of Minerals of Economic Value* (1918), Part II, *Index of Localities* (1921); Part III, *Index of Subjects* (1923); and Part IV, *Palaeontological Index* (1926). Not content with this, Mr. La Touche has since prepared a more detailed *Index to the Memoirs of the Geological Survey of India* up to 1929 (published 1932), and finally the present *Index to*

---

[1] Parts IA and IB were originally published as Part I and Part II, but for some reason the numbering was afterwards changed.

the Records. Owing to the number of papers in the Records, and the variety of subjects that they deal with, this is the largest of the seven volumes. There are one or two good and useful indexes to other geological journals, but none which for fullness and convenience in use are equal to this, except the same author's Index to the Memoirs.

No one who even glances at the seven volumes will have any doubt about the magnitude of the task that Mr. La Touche set himself, but only those who have occasion to use the volumes can fully realize the thoroughness with which it has been carried out. Indian geologists are indeed to be congratulated.

P. L.

THE CAMBRIAN FAUNAS OF NORTH-EASTERN AUSTRALIA, Parts 1 and 2. Reprint from Vol. XI, Part I, Memoirs of Queensland Museum, 17th April, 1936. pp. 59–112, pls. viii–x. By F. W. WHITEHOUSE.

THE first part of this paper describes the stratigraphy of an area of between 50,000 and 60,000 square miles centred on the borders of the Northern Territory and Queensland. Resting on pre-Cambrian sediments the horizontal or low-dipping Cambrian beds now recognized range in age from the top of the Lower Cambrian to the top of the Upper Cambrian, if, as the author supposes without question, the trilobite *Redlichia* really indicates a Lower Cambrian age.

And yet, direct proof of succession is not always available, but various index faunas have been collected from the four series of beds described and these are correlated not only with other Australian occurrences, but with a modified version of Resser's Cambrian Time Scale for the Atlantic Province.

The Templeton Series of sandstones, siltstones, and cherts, which appear to contain limestones only in the west, have been found to comprise four faunal stages ; the interrelationships of these stages is obscure but the *Redlichia* stage, which elsewhere in Australia and in Chosen lies above a *Protolenus* fauna, is considered to be the older. Of the three remaining stages the well-known Templeton River (*Dinesus*) fauna is thought to be the younger, and is compared in age with the *Ctenocephalus exsulans* zone of Scandinavia, sharing with it as it does *Agnostus gibbus* and other early Middle Cambrian fossils.

The Georgina Series is essentially composed of limestone in which seven faunal stages are recognized ; of these the three lower are correlated with the two upper Paradoxides zones of the European Middle Cambrian mainly from the distribution of Agnostid genera and the presence of *Anomocare* ; the four remaining stages are referred to low horizons in the Upper Cambrian.

The succeeding Upper Cambrian Pituri Sandstone-shale Series is so far marked by only one faunal stage containing *Orusia* and trilobites which include the Greenland genus *Elathriella* Poulsen. Away from the main outcrop and occurring as inliers among Cretaceous beds is the Ninmaroo Limestone Series which yields Ellesmeroceratids unassociated with trilobites. This fauna is stated to be of Lower Ozarkian age (pp. 69, 77, 78), though presumably "Upper Ozarkian" or "Lower Canadian" is intended, for the horizon is correlated with the Lower Tremadoc (p. 69) without further comment. The Lower Tremadoc is characterized by the zone of *Dictyonema flabelliforme* which in the American sequence has been claimed to represent the base of Dana's redefined Canadian System; that the Upper Ozarkian and Lower Canadian may be in part synonymous has been suggested by Kobayashi. Perhaps Dr. Whitehouse may amplify his views of the correlation when he comes to describe the Ellesmeroceratids in a later publication.

The palaeontological part of the paper is confined to descriptions of trilobites belonging to Richter's division Eodiscidea. Photographs are given of the types and other specimens of *Microdiscus significans* Etheridge junior which is referred to Walcott's genus *Pagetia*; the distribution of that genus is now extended from Western North America to Australia and India whilst *Pagetia attleborensis* (Shaler and Foerste) of the Atlantic province Lower Cambrian is made the type of a new genus *Hebediscus*.

Seventeen Agnostid species are described, illustrated photographically and distributed among thirteen genera of which seven are new and the remainder are assigned to genera erected by Corda, Jaekel, and Howell. These genera are for the most part relegated to families defined by Professor B. F. Howell and Dr. Whitehouse respectively.

Amid a wealth of interesting Cambrian faunal studies which have recently appeared in the Eastern Hemisphere, this instalment of Australian palaeontology is particularly welcome; in the meantime it is unfortunate that the trilobite name *Anorina* Whitehouse, genotype *Liostracus ? superstes* Linnarsson 1875, is invalid because of one month's priority of *Eoasaphus* Kobayashi (*Jap. Journ. Geol. Geography*, vol. xiii, March, 1936, p. 178), which bears the same genotype.

C. J. S.

Paradoxides oelandicus Beds of Öland with an Account of a Diamond Boring through the Cambrian at Mossberga. By A. H. Westergård. Sveriges Geologiska Undersökning, Ser. C, Avhandlingar No. 394. Stockholm, 1936, pp. 1–66, 12 pl., 8vo, 3 kronor.

When the Swedish Geological Survey in 1922 published Dr. Westergård's excellently illustrated monograph on the Stratigraphy and Trilobites of the Upper Cambrian of Sweden, the reader's appetite was whetted for a similar publication on the Middle Cambrian. We have not been entirely disappointed, for the brochure under review deals with the oldest beds of the Swedish Middle Cambrian as they are developed in the type district, the island of Öland. Despite the unsatisfactory nature of the natural exposures, detailed knowledge of the succession has been gained largely from two carefully collected borehole-cores, occurring 12 km. apart. The author establishes that the Oelandicus Shales are divisible into two zones named from new species of *Paradoxides* and suggests that further research will probably substantiate the validity of these zones on the Scandinavian mainland.

In many ways the fauna is remarkable containing as it does the earliest European true Agnostids, along with survivals from the Lower Cambrian Eodiscid genus *Calodiscus* Howell, with *Paradoxides* species in which, unlike the later species of that genus, the hypostome is separated from the rostrum by a hypostomal suture, Conocoryphids and Solenopleurids; but most unexpected of all, a new species of *Burlingia* (a 13 mm. proparian trilobite) which is almost identical with the only other known species of the genus, namely the genotype *B. hectori* Walcott from the Burgess Shales of British Columbia. The fauna is enriched by several other new trilobite species as well as by a new gastropod genus. Some of the beautiful plates contain photographs prepared by Holm and retouched by Liljevall and include a developmental series of *Paradoxides* which will not improbably produce discussion.

C. J. S.

CORRESPONDENCE.

LATERITE.

Sir,—May I take the earliest opportunity of expressing in your pages my thanks to the Director of the Geological Survey of India and Dr. C. S Fox for the latter's paper on "Buchanan's Laterite of Malabar and Kanara" which has just reached me (*Records, Geological Survey of India*, part 4, April, 1936). The valuable work carried out by Dr. Fox on the type occurrences of laterite was prompted, partly at any rate, by remarks made by me in an earlier volume of this Magazine, and I am sure that all who are interested in laterite will share my feeling of gratitude to him for clearing up the question of the chemical composition of these rocks. I hope to discuss the paper at a later date.

J. B. Scrivenor.

Somerset,
19th August, 1936.

THE

GEOLOGICAL MAGAZINE

VOLUME LXXIII.

No. X.—OCTOBER, 1936.

ORIGINAL ARTICLES.

So-called *Salterella* from the Cambrian of Australia.

By L. F. Spath, D.Sc., F.G.S.

(*a*) Introduction.

THE Lower Cambrian genus *Salterella*, Billings, has lately received a good deal of attention in connection with the problem of the origin of the Cephalopoda. The genus, it may be remembered, was first described by its author as undoubtedly allied to *Serpulites* i.e. a worm-tube, but it was soon transferred by Billings himself to the pteropods. Barrande and Walcott also considered *Salterella* to be related to *Tentaculites* and *Hyolithes*. Clark (1925),[1] who revised the genus, came to the conclusion that *Salterella* was a cephalopod, and not by any means a primitive type, but it did not seem to him to be ancestral to any subsequent form. Poulsen (1927) accepted this view, stating that the cephalopod characters were very conspicuous, but his later (1932) restoration of an East Greenland form, identified with *S. rugosa* from Labrador, is no more convincing than was Clark's restoration of *S. conulata*. Unfortunately, the genotype species of *Salterella* (*S. rugosa* Billings) is still incompletely known and I agree with Teichert (1935) that further investigation is needed before the real nature of *Salterella* can be held to be established. If the "septal necks" are still a doubtful feature and if the very existence of a "siphuncle" is open to question, as Teichert rightly says, it is clearly as premature to visualize *Salterella* as a possible forerunner of the holochoanites (Schuchert, in Schindewolf, 1929) as it is to connect the equally doubtful *Volborthella* with either holochoanites (Teichert and Kobayashi) or orthochoanites (Schindewolf, 1934).

Some of the uncertainty about *Salterella* is due to the fact that it has been made to include a heterogeneous assemblage of unrelated forms. The cones are generally very small and usually poorly preserved and it is perhaps not surprising that organisms of different affinities and even widely different structure have been assigned to this genus. One of these forms is the West Australian "*Salterella*" *hardmani* Foord (1890), which has already been stated by Clark (1925) to be probably distinct generically. By the kindness of Miss Kathleen Prendergast, of the University of West Australia, Crawley, I have lately received many specimens of "*S.*" *hardmani* out of a Cambrian limestone, near Ord River Homestead, East Kimberley; and on preparing thin sections of thirty-five of these little cones (externally more like elongated concretions) it became obvious that they were neither cephalopods nor congeneric with *Salterella rugosa*. Foord's description and illustrations are not only sketchy but misleading; and his type material, in the British Museum (Natural History) consists of weathered sections on the surface of a solid slab of limestone, so that the study of the more favourably preserved new material has proved of the greatest interest. I must express my grateful acknowledgments to Miss Prendergast for submitting the specimens to me, also to Mr. K. P. Oakley, B.Sc., and Mr. A. Reely of the Geology Department of the British Museum (Nat. Hist.) for enabling me to study certain Pteropoda and for helping me with the thin sections; and I hope that the present note, if it does not settle the problem of *Salterella*, will at least simplify it by eliminating from this genus certain alien elements.

---

[1] For reference see list of literature at end.

(*b*) DESCRIPTION.

Foord's original account of "*Salterella*" *hardmani* (Etheridge jun. MS.) stated that the tubes were "of an elongate, conical form, rather rapidly tapering, and straight or slightly curved, the longest about ten lines; each contained several smaller tubes, one within the other, the last of these little hollow cones being the chamber of habitation. The shell was thick and had consequently not been crushed, two or three of the inner tubes retaining their cylindrical form". This description must be considerably amended. The most striking feature of the thin sections is the presence of septation or rather tabulation in one, two, or even three invaginated cones. In most of the specimens the calcareous mud infilling of the cones did not penetrate the tabulate portion which then appears to be solid; but this is probably due to clear calcite having secondarily been deposited in the "chambers". Septation or tabulation, however, may be as distinctly preserved where the "chambers" are filled with mud, while in some cones (upper cone in Fig. 1, *d*) a gradual passage from mud into clear calcite near the apex suggests destruction of the tabulae. Whether the many cones which, like Foord's diagrammatic fig. 1*a*, show no tabulation at all, owe this appearance to similar destruction by the infilling matrix or to solution is doubtful, but perhaps not probable, since there is occasionally only a single septum (Fig. 1, *d*) and since in any case there is the greatest irregularity in the spacing and arrangement of the partitions. In many cases, of course, the tabulate apex is broken off. The infilling, it may be added, was not facilitated by a "siphuncle" or other opening in the septa. Such a "siphuncle" might by some be considered to have been possibly missed in preparing the sections but there can be no doubt that the tabulae are imperforate.

The shape of the septa or tabulae in longitudinal sections also varies greatly. Most are strongly concave, some almost conical, but there are individuals (Fig. 1, *g*) in which the straight tabulae are as geometrical as the rungs of a ladder, though irregularly spaced. These two types of septa are well illustrated in P. Teilhard de Chardin's (1931) figs. 2 and 3 of pl. i. The curvature of the tubes is similarly subject to variation and clearly of little significance. The narrowing of the inner tube in Fig. 1, *e* (and *h* ?) I take to be due to the section being cut at right angles to the plane of curvature which was not the same as that of the outer tube. The apparent constriction of the (fragile ?) larger end in some individuals (Figs. 1, *a*, *h*) may be due either to a similar change of curvature or to crushing. When the cones are well invaginated, i.e. when the curvature of all the tubes is in the same direction, the apical angle seems constant; the variations in the rate of tapering, noticeable especially in polished sections, are due to the obliquity.

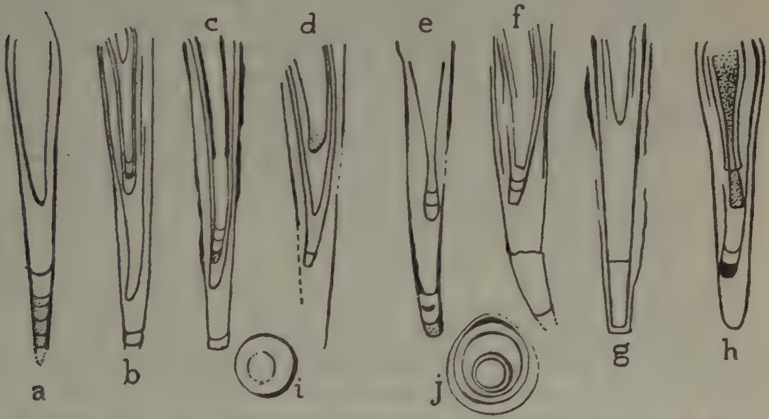
The wall of the cones shows no structure, being merely crystalline calcite, but there is the greatest variation in thickness. The horizontal sections (Fig. 1, *i* and *j*, and Fig. 2, p^1 and p^2) best show the irregularities, but in the longitudinal sections also it can clearly be seen that the walls of the cones pass from extreme thinness to regular or irregular thickening in the most erratic manner. This feature also is illustrated in P. Teilhard de Chardin's excellent photographs. It is not probable that this is entirely a matter of preservation or secondary alteration; for example in section *j* the unusual thickening of the upper side of the second largest cone, or the thin lower half of the inner cone in section *c* is not likely to have been caused by later changes and seems to be original. Whether the discontinuity of the wall of the second largest cone in Fig. 1, *b*, is due to another irregularity or to a subsequent fracture is doubtful. A fracture can be seen in Fig. 1, *f*, but it is now represented by a vein of calcite. This example also has two of the cones almost completely destroyed, mechanically or by solution; in *m* the wider ends of all the tubes have been crushed and are now connected by minute veins of calcite.

The outer tube in all cases is coated with matrix (not shown in the figures *a*–*j*) from which it cannot be separated. In spite of an occasional wrinkly appearance (Fig. 1, *g*), however, the outline suggests that the tubes were smooth, as they undoubtedly are in some other Australian examples of "*Salterella*" *hardmani* in the British Museum. One slab of these, from north of Nelson Creek, Negri River, Northern Territory, consists of a pinkish, marmorized limestone, with the little cones weathered out, more or less perfectly, and sometimes even retaining the horizontal striae of growth, but not showing the internal characters so well as the loose Kimberley specimens. Another slab of a siliceous limestone, from Mount Panton, Northern Territory, is similarly covered with numerous weathered-out cones, smooth, and occasionally displaying invaginated smaller tubes, but no internal structure was visible in those I sectioned. A similar slab was figured by Wade (1924), enlarged probably more than stated (× 1½).

(*c*) AFFINITIES.

A number of the smaller cones on these slabs are single and either hollow or with a few tabulae and they represent the young. But among the new material I sectioned there are a few single cones quite as large as the average adult (15–20 mm.) here illustrated which makes it almost certain that the smaller cones got into the larger tubes by accident, just as small ammonites are often found inside larger shells. Moreover, in some South Australian rocks, from near Muponga, about 38 miles south of Adelaide, with what appear to me to be typical examples of "*Salterella*" *hardmani*, in addition, perhaps, to the doubtful "*S.*" *planoconvexa* Tate, there are individuals enclosing two smaller cones; but these lie side by side instead of being telescoped. However difficult it may seem to believe that five tubes, as in Fig. 1, *j*, were washed into one another by accident, yet the very large percentage of telescoped cones, as compared with single tubes, is accounted for by their greater resistance to crushing during formation of the ooze. This invagination of hollow cones is not unknown in other pteropods and was well illustrated for example by Hall (1888) in the case of *Tentaculites gyracanthus* (Eaton). It was described as "not an infrequent mode of occurrence in this formation where the rock is sometimes almost wholly made up of these bodies". This applies equally to the Australian rocks and explains the apparent difference between the loose, weathered out Kimberley cones and the natural sections in the rock where single cones and masses of broken tubes are as common as invaginated or telescoped examples. It will be noticed that, as in *Tentaculites*, the invagination is far less regular than envisaged by Foord and quite different from the neat cone-in-cone structure that has been suggested for *Salterella*. Moreover, in at least one of my specimens (Fig. 2, *k*) the inner cone is inverted, as in some of the sections figured by P. Teilhard de Chardin (1931).

If Foord's interpretation be accepted and the invagination be considered original, not accidental, the question of how the animal lived arises. In the case of the somewhat similar "*Salterella*" (now *Polylopia*) *billingsi* Safford, consisting of an almost solid mass of tightly packed, fluted, cones, inside one another, it was suggested by Clark that the inner shell was the oldest and that "each successive shell without was younger than the one it surrounded". "For," he added, " it is hard to understand how any process of shell secretion could accomplish the formation of an inner cone fitting closely within an already existing one. Moreover, no good purpose would seem to be served by this process, for the resulting inner chamber would be made successively smaller and smaller, while the animal was presumably growing larger and larger." The examples of "*Salterella*" *billingsi* (of Trenton or Middle Ordovician age) which I have examined were too completely mineralized to reveal much of their inner structure, but it seems to me that such straight fluted cones would naturally fit much better into one another than the curved tubes of "*Salterella*" *hardmani* or the transversely ringed cones of *Tentaculites*. In any case, if the animal is presumed to have lived wholly outside the shell in the adult I do not see why the outer cone should not have been a place of refuge at first. If the telescoping of the cones in "*S.*" *hardmani* were not accidental it could be suggested that the first cone, i.e. the outer, was like an *Orthoceras* shell, with or without a few tabulae, and that successive inner cones, with or without tabulae, were secreted by the gradually receding animal, as hydrostatic considerations required adjustments of weight, until, in the adult, the animal was almost entirely outside the shell. It is possible that the shell was then a sort of stabilizer, perhaps facilitating vertical or other movement in a pelagic pteropod; and, however improbable, it is not altogether impossible to visualize a form like *Styliola* or at least a pteropod of similar outward appearance with a series of weighted cones.



TEXT-FIG. 1.—*Biconulites hardmani* (Foord). Lower (?) Cambrian. Near Ord River Homestead, East Kimberley, Western Australia. Eight longitudinal and two transverse sections, enlarged by about 3.

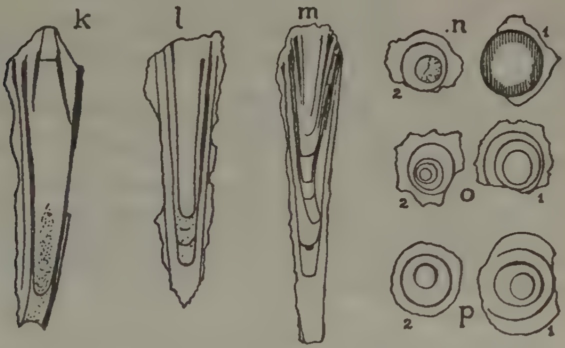
Since the telescoping, however, is almost certainly accidental, the shell must have been like that of *Hyolithes* or *Tentaculites*, but with a slightly tabulate apex. Clark had already pointed out that septa are not entirely unknown among pteropods, and *Hyolithes* occasionally possessed one or more near the apical end. But these are complete, with no perforation, and in no way analogous to a cephalopodan septum so that "*Salterella*" *hardmani* is clearly not a cephalopod.

(*d*) SYSTEMATIC POSITION.

"*S.*" *hardmani* cannot be accommodated in the genus *Salterella*. Not any amount of weathering could transform the telescoped cones of "*S.*" *hardmani* into a succession of short cones such as characterize *S. rugosa* Billings, apart from the presence of tabulation in the former and perhaps of a doubtful siphuncle or at least median rod (or columella ?) in the latter, if the Levis (Quebec) and East Greenland forms described as *Salterella* should prove congeneric with the Labrador type of *S. rugosa*. Still more doubtful species of this genus are *S. maccullochi* (Salter) and *S. curvata* Shaler and Foerste, which, like other forms now kept distinct from *Salterella*, may turn out to represent yet different genera, as perhaps do the Comley forms described by Cobbold (1921). Specimens before me of *S. pulchella* Billings, from the type locality (L'Anse au Loup, Labrador) are as difficult to interpret as those of *S. maccullochi*, from quartzites at Loch Eribol, and other localities in Sutherland, but since they are apparently not very close to "*S.*" *hardmani* they need not be discussed in detail.

Even if there be no doubt, then, that the alleged cone-in-cone structure is accidental, it is necessary to find a new genus for "*Salterella*" *hardmani* Foord. I can see no essential difference between typical Australian examples of this species and the enigmatic pteropod-like fossil from China, described by P. Teilhard de Chardin (1931), except possibly the larger size of the latter (up to 40 mm.) and the appearance in the weathered-out condition; for none of the Australian specimens on the slabs already referred to shows an operculum-like termination at the wider end, comparable to P. Teilhard de Chardin's fig. 1*a* (p. 180); but the loose Kimberley specimens all pass into soft mud at the larger end. It seems to me, however, that this author's interpretation of his Chinese form must be questioned as much as the presence of a central tube in the cones, his fig. 3 of pl. ii showing a typical "*Salterella*" *hardmani*. The peculiar appearance of some of his other sections is merely due to their having been cut obliquely and they can almost all be matched by Australian polished sections before me, though inversion of cones is not so common in "*S.*" *hardmani* (or in *Tentaculites*).

With regard to the name to be adopted, Grabau's (1929) *Teilhardoceras* would appear to have priority before *Biconulites*, P. Teilhard de Chardin (1931); for, although the fossil was not figured by Grabau, it was defined. The mere fact that the interpretation was wrong and the name was put forward provisionally does not invalidate it. But not only was the diagnosis incorrect in the most important detail, so that nobody could have recognized the fossil, but the name *Teilhardoceras* was not attached to any species and was, in reality, given to a hypothetical cephalopod rather than to Teilhard's unnamed Cambrian pteropod, which only "suggested" such a structure as Grabau postulated for the primitive Holochoanites. I thus accept Teilhard de Chardin's *Biconulites* for "*Salterella*" *hardmani*, and it seems to me probable that *B. grabaui* will turn out to be a synonym of *B. hardmani*; but whether *Biconulites* is exclusively Lower Cambrian I am not prepared to say.



TEXT-FIG. 2.—*Biconulites hardmani* (Foord). Lower (?) Cambrian. Near Ord River Homestead, East Kimberley, Western Australia. Three longitudinal and three pairs of transverse sections, n^1, o^1, p^1 being at the wider end, n^2, o^2, p^2 lower down in the same three individuals, all enlarged by about 3.

It is not improbable that "*Salterella*" *planoconvexa* Tate (1892), an "invaginated *Hyolithes*", will have to be included in the genus *Biconulites*, if the description is correct. But not one of the many and apparently very varied shells in the South Australian (Muponga) rocks already referred to can be definitely identified with Tate's type figure, and even those elongated cones that show a mesial furrow, like a miniature *Belemnopsis*, may be merely crushed examples of *B. hardmani*. This seems to differ from the more cylindrical forms of *Hyolithes* or from *Hyolithellus*, chiefly in the absence of an operculum, and it is distinguished from *Camerotheca* Matthew merely by its less fusiform shape, and, apparently, by the absence of the larval tubule. Reference of *Biconulites* to the Hyolithidae, Nicholson is, therefore, suggested; for although in the Tentaculitidae also, the posterior end of the shell may often be filled with calcareous deposits or tabulae, they are thick-shelled, like the Torrellellidae Holm, and Salterellidae Walcott.

LITERATURE.

Clark, T. H., 1925. "On the Nature of *Salterella*," *Trans. Roy. Soc. Canada*, 3rd series, xix, section iv, 29–41, 2 plates.

Cobbold, E. S., 1921. "The Cambrian Horizons of Comley (Shropshire) and their Brachiopoda, Pteropoda, Gasteropoda, etc," *Quart. Journ. Geol. Soc.*, lxxvi, 359–361.

Foord, A. H., 1890. "Description of Fossils from the Kimberley District, Western Australia," Geol. Mag., dec., III, VII, 98, pl. IV, Figs. 1, 1*a*, *b*.

Grabau, A. W., 1929. "Terms for the Shell-Elements in the Holochoanites, *Bull. Geol. Soc. China*, viii, 121.

Hall, J., 1888. "Palaeontology of New York," v, pt. ii, Supplement, 5, pl. cxiv, fig. 12.

Poulsen, C., 1927. "The Cambrian, Ozarkian and Canadian Faunas of North-west Greenland," *Medd. om Grønl.*, lxx, 251.

—— 1932. "The Lower Cambrian Faunas of East Greenland," *Medd. om Grønl.*, lxxxvii.

Schindewolf, O. H., 1929. "Zur Systematik und Stammesgeschichte der ältesten Cephalopoden," *Zeitschr. f. Geschiebef.*, v, Heft 4, 178.

—— 1934. "Bau und systematische Stellung der Gattung *Volborthella* Schm.," *Pal. Zeitschr.*, xvi, 193.

Tate, R., 1892. "The Cambrian Fossils of South Australia, *Trans. Roy. Soc. Sth. Austr.*, xv, pt. ii, 186, pl. ii, figs. 3, 3*a*, *b*.

Teichert, C., 1935. "Structures and Phylogeny of Actinoceroid Cephalopods," *Amer. Jl. Sci.*, xxix, 21.

Teilhard de Chardin, P., 1931. "On an Enigmatic Pteropod-like Fossil from the Lower Cambrian of Southern Shansi, *Biconulites grabaui*, nov. gen., nov. sp." *Bull. Geol. Soc. China*, x, 179–184, pls. i–ii.

Wade, A., 1924. "Report on Petroleum Prospects, Kimberley District, Western Australia and Northern Territory," *Parliam. P., Commonw. Austral.*, 1923–4 (Melbourne), 44, pl. iv.

An Ordovician Species of *Chaetetes*.

By Kenneth P. Oakley, Department of Geology, British Museum (Natural History).

(PLATE XII.)

THE fossil material collected from the Ordovician limestones of Akpatok Island, N.W.T., by Mr. Ian Cox during the Oxford Hudson Straits Expedition in 1931, included a specimen whose affinities could not be determined from a superficial examination. In asking me to report on the Polyzoa from these rocks, Mr. Cox suggested that I might also investigate this doubtful form, since it resembled in many respects certain massive Polyzoa. Critical examination by means of thin sections has shown, however, that it is not a Polyzoan but a Tabulate Coral referable to the genus *Chaetetes*.

In spite of its rather poor preservation, this specimen seems worthy of description in view of the fact that this genus has only once previously been recorded from a Lower Palaeozoic formation (Whiteaves, 1897, 238–9).[1]

---

[1] For references see list of literature at end of article.

I am indebted to Mr. Cox for supplying me with details of the horizon and associated fauna, and to Dr. H. Dighton Thomas for helpful discussion and advice on various points.

CLASS ANTHOZOA

Genus Chaetetes Fischer MS. in Eichwald (1829, "Zoologica specialis" . . . pt. i, p. 197).

Genosyntypes: *C. fastigiatus*, loc. cit., p. 197: Carboniferous, Moscow; *C. cylindraceus*, loc. cit., p. 197; pl. iii, fig. 8: Carboniferous, Moscow.

Genolectotype (here chosen)[1]: *C. cylindraceus*.

Chaetetes akpatokensis sp. nov.

Plate XII, Figs. 1 and 2.

Material.—One specimen forming the base of attachment of a large colony of *Calapoecia canadensis* var. *anticostiensis* Billings (Cox, 1936).

Diagnosis.—*Chaetetes* with low tumular corallum consisting of vertically radiating corallites with polygonal or oval cross-section, varying in average diameter from 0·15 mm. in the proximal, to 0·25 mm. in the distal region.

Description.—As far as it is preserved the corallum is 2 cms. wide and forms a curved laminar expansion 3–5 mm. thick, with a smooth, gently convex surface and a slightly irregular, concave base which is unattached and apparently covered by a thin holotheca.[2] The corallites are prismatic and continuous throughout their length. In section the walls of adjacent corallites appear to be single (i.e. completely amalgamated), but this may be the result of recrystallization (see below). They are relatively wide, the average thickness being 0·05 mm., and the maximum about 0·07 mm.

In *transverse section* (Pl. XII, Fig. 2) it is clear that initially the corallites are hexagonal or pentagonal in outline, but that in most cases the angles have become rounded, probably through the deposition of auxiliary sclerenchyme. The corallites increase in average diameter with maturity; in the proximal region of the corallum the average diameter is 0·15 mm. and in the distal region of the order of 0·25 mm. There is, however, a tendency for the corallites to show greater elongation along one axis, so that they present an oval or elongated polygonal outline. This becomes particularly marked in the mature region of the corallum. The distal region is also characterized locally by a meandrine condition of the corallites. This condition, which is due to failure to develop a separating wall in the course of increase, is found in all Carboniferous species of *Chaetetes*, and is generally taken to be diagnostic of the genus. Where the failure has been complete the joint corallites have an enormously elongated calice, twice or thrice the length of the calice of a normal single corallite. In cases where there has been partial separation of an offset, the incompletely developed dividing wall has the appearance, in transverse sections, of a septal spine. True septal structures are, however, absent.

---

[1] Smith and Lang (1930, 188) selected *C. radians* Fischer v. Waldheim as genotype from among the species mentioned by Fischer in 1830, supposing that he established *Chaetetes* in that paper, and in ignorance of Eichwald's publication of 1829.

[2] The terminology proposed by Miss D. Hill (1935) is here followed so far as it is applicable to Tabulate forms.

In *longitudinal section* (Pl. XII, Fig. 1) the corallites are seen to be crossed by thin complete tabulae which are straight or concave distally. They show an uneven distribution, being alternately close together in groups of two or three, and widely separated by intervals of 0·6 mm. or more. The same alternation has been observed (Smith and Lang, 1930, 190) in *C. radians* Fischer v. Waldheim; it is, however, also found in many other Tabulate Corals, and is regarded as a reflection of varying environmental conditions rather than as a diagnostic character. There is a tendency for the tabulae to occur at the same levels in adjacent corallites, which gives the corallum a stratified appearance in longitudinal sections. Mural pores have not been observed.

Preservation.—In thin sections the corallite walls show patchy inclusions of dark granular material. In transverse sections these show up as a series of irregularly spaced spots. These spots have indefinite edges, and shade off into the clearer though minutely speckled sclerenchyme which borders them. In longitudinal sections the dark material is seen to form strands and elongated patches of a variable character extending down the middle of the corallite walls, and occupying more than half their width. In view of the recrystallized condition of the walls it is most improbable that the patches are an original histological structure. They probably consist of impurities introduced soon after the death of the colony by solutions percolating along the divisional parting of adjacent corallite walls. Subsequent recrystallization would have segregated the impurities and obliterated any trace of the origina wall parting.

Horizon.—" Pink Band," 450 feet above mean sea-level, Akpatok Island, Ungava Bay, Canadian North-Western Territories. The associated fauna includes: *Ceraurus tuberosus* Troedsson, *Ceraurinus icarus* (Billings), *C. daedalus* Cox, *Illaenus eucentrus* Troedsson, *Calapoecia canadensis* var. *anticostiensis* Billings (Cox, 1933 and 1936). The " Pink Band " lies below the beds with *Beatricia undulata* Bill. (Richmond), and above the bed with *Shamattawaceras* cf. *ascoceroides* Foerste and Savage. It probably should be included with the latter, which may tentatively be correlated with the Shamattawa limestone of the region west of Hudson Bay (Foerste and Cox, 1936).

Holotype.—Sedgwick Museum, Cambridge, A. 6762 *a* and sections A. 6762 *b–e*.

General Remarks.—The Akpatok specimen agrees closely with *C. perantiquus* Whiteaves (1897, 238–9, figs. 17–19) as regards general structure, but differs from it in (1) the smaller size of the corallites,[1] (2) the less regular arrangement of the tabulae, and (3) the smaller degree of sclerenchymal thickening of the corallite walls. The Akpatok specimen is referred to a new species mainly on the basis of the difference in the size of the corallites, the other differences being quite possibly individual, rather than specific, in character.

In describing *C. perantiquus*, Whiteaves states that at the surface of the corallum each corallite is surrounded by a depressed space or groove. This conclusion was not based, apparently, on direct observation of the surface of the corallum, but was deduced from the occurrence of dark material along the middle of the corallite walls in transverse sections, the assumption being that it was sediment filling spaces between the corallites. It appears from one of Whiteaves' figures (1897, fig. 17) that the dark material occurs in patches almost identical with those observed in the walls of *C. akpatokensis*. As already pointed out for the latter, the material may well have been introduced along an original plane of parting between the walls of adjacent corallites. It has been claimed (Nicholson, 1879, 27; Okulitch, 1935, 50) that in true *Chaetetidae* the walls show no divisional parting, but it still has to be proved that the apparent complete amalgamation is not always the result of recrystallization.

C. perantiquus was recorded from the Lower Fort Garry beds of Manitoba. Although the faunas of these beds were described by Whiteaves as of Black River (Mohawkian) age, in the opinion of Bassler (1915, 1458) at least part of the material must have been derived from a Richmond horizon.

Chaetetes akpatokensis and *C. perantiquus* are the only known pre-Carboniferous species of *Chaetetes*,[2] and the lack of material makes it impossible to decide whether they are directly connected with the Carboniferous forms, or whether they are homeomorphs derived at an early stage from a Favositid stock through pursuance of a meandroid trend. In view of the " progressive " or trend-like character of the features relied on for the diagnosis of *Chaetetes*, it is possible that the genus as at present defined may be polyphyletic. However, there appears to be no criterion at present which makes it possible to separate generically these Ordovician corals from Carboniferous species of *Chaetetes*.

LITERATURE.

BASSLER, R. S., 1915. " Bibliographic Index of American Ordovician and Silurian Fossils," *U.S. Nat. Mus. Bull.* 92.

COX, I., 1933. " Richmondian Trilobites from Akpatok Island," GEOL. MAG., LXX, 359–373.

—— 1936. " Revision of the Genus *Calapoecia* Billings," *Canadian Nat. Mus. Bull.* 80, Geol. series 53.

---

[1] In *C. perantiquus* the average diameter of the corallites is given as 0·5 mm.

[2] Numerous Lower Palaeozoic forms have been referred erroneously to *Chaetetes* in the past; these have proved in most cases to be Polyzoa.

Foerste, A. F., and Cox, I., 1936. "Cephalopods and a *Beatricea* from Akpatok Island," Geol. Mag., LXXIII, 289–307.

Hill, D., 1935. "British Terminology for Rugose Corals," Geol. Mag., LXXII, 481–519.

Nicholson, H. A., 1879. *On the Structure and Affinities of the "Tabulate Corals" of the Palaeozoic Period.* Edinburgh.

Okulitch, V. J., 1935. "Tetradidae—A Revision of the Genus *Tetradium*," *Trans. Roy Soc. Canada*, xxix, Sec. iv, 49–74.

Smith, S., and Lang, W. D., 1930. "Descriptions of the Type-Specimens of some Carboniferous Corals of the Genera '*Diphyphyllum*', '*Stylastraea*', *Aulophyllum*, and *Chaetetes*," *Ann. Mag. Nat. Hist.*, Ser. **10**, v, 177–194.

Whiteaves, J. F., 1897. "Palaeozoic Fossils," *Geol. Surv. Canada*, iii, part 3.

EXPLANATION OF PLATE XII.

Chaetetes akpatokensis sp. nov.

Fig. 1.—Slightly oblique longitudinal section of the holotype, × 10. From an elevation of 450 feet, Akpatok I., N.W.T. Sedgwick Museum, A. 6762*c*.

Fig. 2.—Transverse section of the holotype, × 25. Sedgwick Museum, A. 6762*d*.

Recent Additions to the Albian Ammonoid Faunas of Folkestone.

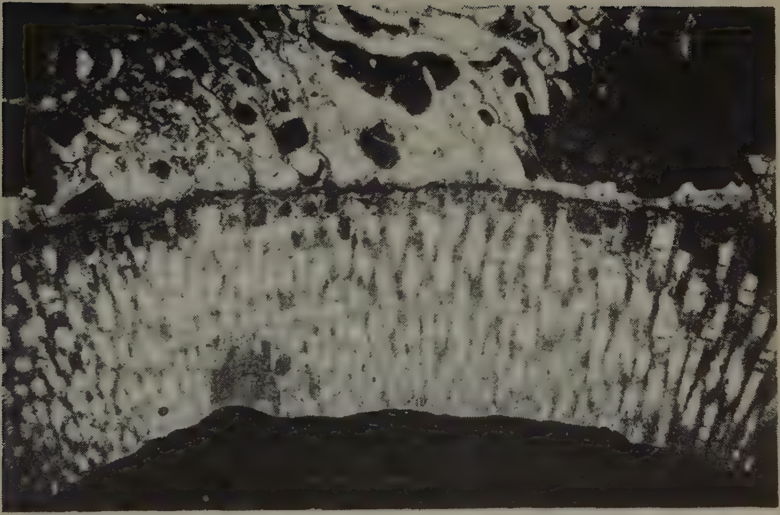
By R. Casey.

FROM a standpoint of stratigraphy, geological interest in this district is centred around the Folkestone Sands; for since the Gault above is of Middle and Upper Albian age, and the Sandgate Clay below is undoubtedly Aptian, the age of the first mentioned deposit is somewhat problematical. The possibility of a Lower Albian age for the major part of these Folkestone Sands had been suggested as early as 1925,[1] and with the subsequent discovery of *Leymeriella regularis* (d'Orb.) (index fossil of the highest Lower Albian zone), in the uppermost stone bands of this deposit, this view was apparently confirmed.

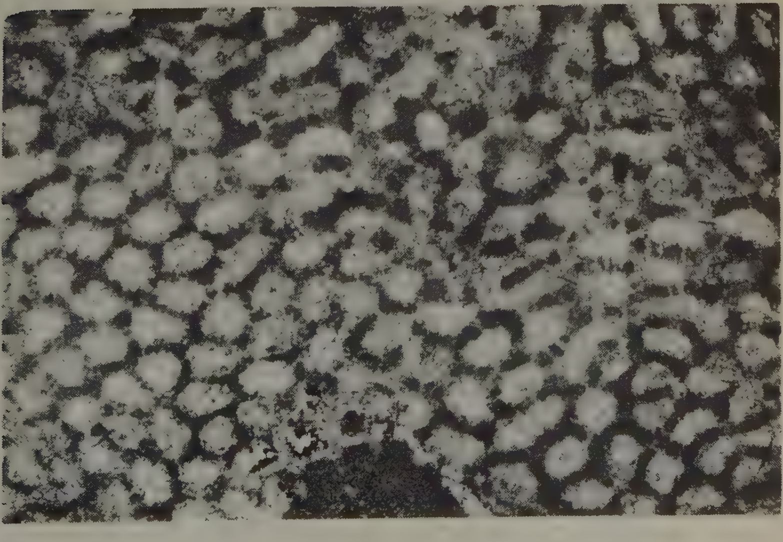
But observation and collecting have since been extended to a number of exposures, ranging from Brabourne (near Ashford), to the Folkestone coast, and some conclusive data regarding the age, and the distribution of the faunas of the Folkestone Sands has been obtained. Shortly, I hope to publish complete details of this work, with descriptions of the critical sections, etc.; meanwhile as attention has already been directed to some of the discoveries of ammonoid faunas[2] it seems advisable to treat these separately. Accordingly the Albian forms from this formation will be recorded together with new material from the Gault.

[1] L. F. Spath, in Walton, "Folkestone and the Country Around," *Folkestone Nat. Hist. Soc.*, 1925.

[2] L. F. Spath, "Field Meeting at Folkestone," *Proc. Geol. Assoc.*, xlvi, 1935, 429–431.



1 ×10



Photos. J. Rhodes. 2 ×25

CHAETETES AKPATOKENSIS sp. nov.

FOLKESTONE SANDS.

(1) *Milletianus* and *regularis* zones.

Following the recent discovery at Sandling (near Hythe) of a *Hypacanthoplites* of the group of *H. milletianus* (d'Orb.) in place (i.e. below the *regularis* level), and still comparatively high up in the Folkestone Sands, collecting at this locality was intensified, for it was realized that we now had the attractive possibility of bridging over for the first time the enormous time interval separating the latest Aptian faunas from the earliest known Albian examples of this country. Unfortunately in this respect we were to be disappointed, for although further ammonoid faunas were brought to light, they proved to be of uppermost Aptian age, and therefore substantiated this gap in the British sequence. However, despite that we have been able to extend the Aptian high into the Folkestone Sands, what is more important, we have obtained the first indication of a *milletianus* fauna in this country.

At Sandling, some 15 feet of sand and carstone represent this Leymeriellan (upper Lower Albian) stage of the Folkestone Sands; and from here we have obtained, in addition to the above-mentioned *Hypacanthoplites*, fragments and one complete body chamber of an ammonite provisionally named *Douvilleiceras*? (or *Acanthoplites*?).

As this Leymeriellan strata approaches the coast it thickens rapidly, and I judge it to attain a maximum development of 30 feet near Cheriton. At any rate, traced along the coast to Folkestone, from a point opposite Cheriton, it thins out again slowly, and in the well-known cliff section east of Folkestone Harbour, Lower Albian fossils are not found below a depth of 20 feet. In the Dover boring, 7 miles farther along the coast, the Folkestone Sands have entirely disappeared.

It was in this East Cliff section near the Harbour, 6 feet from the top, that *Leymeriella regularis* (d'Orb.) was discovered, but at 10 feet down several examples of *Sonneratia kitchini* Spath, and one specimen of an immature *Beudanticeras* have since been collected. The occurrence also in this section (20 feet down) of a *Douvilleiceras* of the group of *D. mammillatum* (Schloth.) is not without interest, for it indicates a still closer connection with the uppermost few feet of sand in which *D. mammillatum* first becomes abundant.

(2) *Mammillatus* zone.

This important horizon also attains its maximum development (10 feet of sand with two lines of nodules) at Cheriton, and is characterized by a wealth of new forms of basal Middle Albian age. It is more usual to unite this *mammillatus* zone with the Gault formation, following Jukes-Browne,[1] but this is purely a matter of stratigraphical convenience, and the writer prefers to adopt the more natural classification of Price[1]. For it is worthy of note that the appearance of the Middle Albian fauna in this district was not coincident with the oncoming of the Gault Sea and its new conditions.

---

[1] A. J. Jukes-Browne, "Cretaceous rocks of Great Britain," i, *Mem. Geol. Surv.*, 1900.

In the East Cliff section this bed comprises 6 feet of sand with a line of fossiliferous nodules. Due to the general north-east dip of this district, this *mammillatus* zone declines to the shore just beyond the foot of Copt Point, and at low tide exceptional facilities for collecting are provided here. From the reefs thus exposed the following fauna has been obtained :—

Douvilleiceras mammillatum (Schloth.).
,, ,, var. *baylei* Spath.
,, *monile* (J. Sow.).
,, aff. *inaequinodum* (Quenstedt).
Beudanticeras ligatum (Newton and Jukes-Browne).
,, *dupinianum* (d'Orb.).
Cleoniceras aff. *cleon* (d'Orb.).
,, cf. *quercifolium* (d'Orb.).
Protohoplites puzosianus (d'Orb.).
,, spp. aff. *puzosianus* (d'Orb.).
,, *raulinianus* (d'Orb.).
,, ,, var. *elegans* Spath.
,, spp. aff. *raulinianus* (d'Orb.).
Anahoplites sp. nov.
Sonneratia sp.
Protanisoceras raulinianum (d'Orb.).
,, ? sp. nov. ?
Gen. nov. ? (" *Protanisoceras* ") sp. nov.
Helioceras spp.

The heteromorphous ammonoids of the above list (*Protanisoceras*, *Helioceras*, etc.) will be dealt with in Dr. Spath's " Monograph of the Gault Ammonoidea " (Palaeontographical Society), so no comment is here necessary. However, among the new material from this bed we have to record a specimen of *Sonneratia*. This genus is known from a similar horizon in Bedfordshire, and its presence here is yet another link with the Leymeriellan assemblage below. Also, among the several examples of *Cleoniceras* brought to light from this *mammillatum* zone is one new species for this country, namely *C.* cf. *quercifolium* (d'Orb.). Dr. Spath tells me that the example I sent him is very close to examples from the Ardennes in his own collection, but slightly less so to d'Orbigny's diagrammatic figure.

Of especial interest is the discovery of *Anahoplites* sp. nov. in this bed. This new ancestral form is a forerunner of the well-known Gault species *Anahoplites planus* (Mantell). This latter has been found together with the previously earliest known *Anahoplites*

---

[1] F. G. H. Price, " The Gault of Folkestone," *Quart. Journ. Geol. Soc.*, 30, 1874, 342–368.

(*A. mimeticus* Spath) as low as the Carstone (*benettianus* zone) of Niton, Isle of Wight. Unfortunately the base of the Folkestone Gault is non-sequential. Even the line of pyritic nodules (i.e. the base of the true Gault of Price) is still of *mammillatum* age; and while it has yielded, in addition to this last index fossil, *Protohoplites* and lamellibranchs, there is no trace of the normal following *inaequinodus* or this next higher *benettianus* zones. Extensive collecting has even failed to produce a single example of *Anahoplites* from the following *dentatus* bed here, but it is abundant in the *intermedius* zone above. Here, it is associated with early forms of its offshoot *Dimorphoplites*, and hereafter we do not lose sight of this genus *Anahoplites* until we reach the *aequatorialis* level in the Upper Albian.

GAULT.

The abundance, variety, and beauty of preservation of these Middle Albian faunas from the Gault Clay is a striking contrast to the few fragmentary Lower Albian forms found in the Folkestone Sands below. The nomenclature of the English Gault ammonites, and the general zonal scheme of the Albian stage have now been placed on a much securer basis, but only those zones which have yielded new material concern us here.

(1) *Dentatus* zone.

Although the search for *Anahoplites* in this bed was without success, two fragments of *Oxytropidoceras* brought to light during this search seem worthy of record. Despite that the only two examples of this genus in the Price collection (subsequently named *O. cantianum* Spath) are from the extreme top of the Lower Gault (*cristatum* zone) the presence of the genotype, *Ammonites roissyanus* d'Orb. in the *dentatus* bed, far below, appears to have been known to Price. At least, he lists it from this horizon and cites it as one of the rare exceptions to the rule that carinate ammonites only occur in the upper part of the Folkestone Gault. The non-hoplitid ammonite fauna of the Folkestone *dentatus* zone is now:—

Oxytropidoceras roissyanus (d'Orb.).
,, aff. *cantianum* Spath.
Pictetia astieriana (d'Orb.).
Protanisoceras ? sp. nov. ?
Hamites sp.

The range of *O. cantianum* Spath is then unusually long, but the sporadic appearance of Dipoloceratids is not confined to the genus *Oxytropidoceras*. It will be recalled that *Dipoloceras cornutum* (Pictet) restricted to the *lautus-nitidus* zone of the Folkestone section has been found in the much higher *cristatum* zone elsewhere, while even *D. delaruei* (d'Orb.) only known from the basement of bed 4 at the English type section is said to be common in the *dentatus* zone (bed 1) of some continental localities.

(2) *Cristatus* zone.

In the Folkestone section this important junction bed consists of two lines of nodules, 9 inches apart, and from these nodules and the clay between a prolific fauna comprising genera common to both the Lower and Upper Gault may be obtained.

The ammonites already mentioned have shown this Folkestone section to have a greater affinity to its Continental representatives and their ammonite faunas than previously realized, but now we have a really interesting discovery to record from this *cristatus* zone. This is an ammonite recognized by Dr. Spath as a probable new species of *Gastroplites*, a genus only known from the Canadian Western Interior, and it is to be described by him.

The writer has nothing of importance to record from the Upper Gault here, but it may be mentioned that a Cambridge Greensand species, *Callihoplites* aff. *glossonotus* (Seeley) has been found in the nodule bed at the base of bed 12 (*aequatorialis* zone). Other Cambridge Greensand forms, principally species of *Mortoniceras*, have already been recorded from this horizon by Dr. Spath, to whom the writer wishes to extend his thanks for kindness in identifying the major part of the faunas here discussed.

Symplectite-bearing Nodules in the Ardgour Marble, Argyllshire.

By H. I. Drever, Department of Mineralogy and Petrology, Cambridge.

1. Introduction.

On Sheet 53 of the 1 in. Geological Survey Maps of Scotland an outcrop of marble is indicated at the mouth of the Coire Dubh. Nodules embedded in this marble are examined in this paper.

The Coire Dubh is the perfect glacial cirque overlooking Loch Linnhe from above the village of Ardgour.

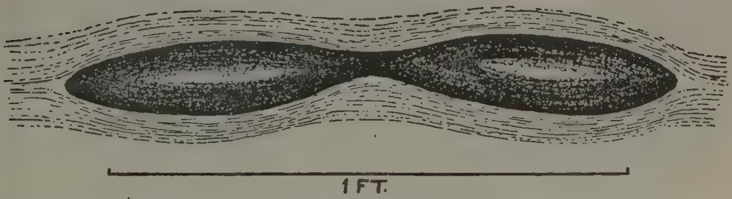
The Ardgour area was mapped in 1897 by J. S. Grant Wilson, whose map records how this outcrop is located at the margin of the great Glen Scaddle dioritic mass and entirely surrounded by it.

The marble, which is exposed in the burn leading from the corrie, is well bedded in appearance and lies, as a whole, fairly flat. In many places it is strongly folded and puckered. A varied and extensive assemblage of hybrid types is developed along the contact with the diorite. Where the diorite is uncontaminated it is here a massive rock without any conspicuous foliation.

In their low dip the marble and calc-silicate rocks within the diorite conform with foliated felspathic gneisses below the diorite.

Below these again are felspathic granulites and coarse felspathic quartzites belonging to the Moine Series and increasing in dip towards the Great Glen Fault.

Two large roughly lenticular nodules, separated by about 3 yards near the northern end of the exposure are very coarse-grained and similar in type. A third large nodule is distinctive. It is exposed at about 10 yards downstream from the others and has weathered out strongly as two perfect lenticles or augen joined together (Text-fig. 1), the banding in the surrounding rock conforming with their shape. Contrasted with that of the other two nodules the rock of this nodule is relatively fine-grained and homogeneous, and the nodule is of slightly smaller size. These nodules are quite isolated in the surrounding marble; they are in no apparent way connected with the diorite, although the exposure of rock could hardly be better, and they bear practically no resemblance to the hybrid types. Numerous small nodules, not more than the order of 2 inches in size, weather out as little lenticular excrescences.



TEXT-FIG. 1.—Diagram showing augen of hard black rock weathered out of banded marble.

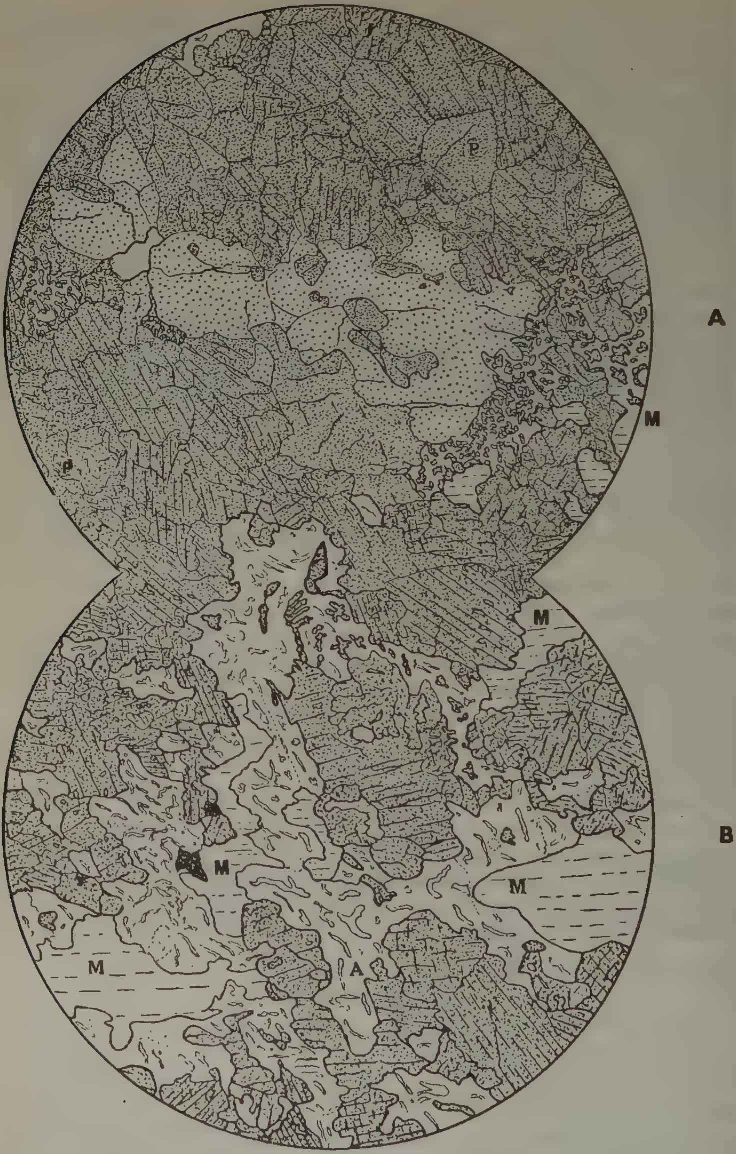
The character of the normal marble and calc-silicate rocks will be presented in more detail in a future paper. Within 2 feet of any of the nodules the rock consists of stout laths of wollastonite, light brown garnet, and subordinate lime scapolite, microperthite, calcite, and a black pyroxene which is usually pink in thin section. Calcite and microperthite may become important components.

2. PETROGRAPHY.

(1) *The Fine-grained Nodule.*

In hand specimen this is a black rock with occasional white streaks or patches and a sporadic distribution of very irregular, brown vesuvianites. Separating this black rock from the wollastonite-garnet-scapolite hornfels is a persistent zone, from ¼ in. to ½ in. in width, mainly composed of microperthite as a mosaic of crystals averaging about ¼ mm. in size.

A pink to colourless pyroxene is the characteristic mineral. It forms either irregular xenoblastic crystals set in a symplectitic



Text-fig. 2.—A. Pflaster arrangement of pyroxenes at the top, and vesuvianite associated with a small amount of anorthite-pyroxene symplectite in the centre. There is also some microperthite optically continuous with that of B. B. One large microperthite crystal (horizontal cleavage) in separated portions intergrown with anorthite-calcite-orthocase symplectite. The anorthite has complicated twinning and practically no regular boundaries. The pyroxenes are irregular. Scale × 30.

P = Pyroxene. A = Anorthite. M = Microperthite.

base of anorthite, calcite, and orthoclase, added to, or in place of which, may be found microperthite or vesuvianite; or it forms, more rarely, small areas of crystals arranged in pflaster fashion to the exclusion of any other mineral (Text-fig. 2).

The anorthite ($\alpha = 1{\cdot}575$, $\gamma = 1{\cdot}587$)[1] occasionally contains ragged little patches of calcic scapolite which have apparently arisen in place of enclosed threads of calcite which, in such cases, have disappeared. Normally the vesuvianite forms poeciloblastic crystals enclosing rounded or shapeless pyroxenes but never felspars. It is optically negative and uniaxial. Rarely dactylites of colourless pyroxene set in anorthite are derived from the vesuvianite margin. The host of this symplectite is found continuous with a larger anorthite. Untwinned microperthite ($\beta = 1{\cdot}525$) is sporadic in its distribution and is found in all dimensions up to 2·5 by 1·5 mm. It may show uneven extinction. The threads of orthoclase enclosed in anorthite may extinguish with microperthite. The anorthite-calcite-orthoclase symplectitic association is so persistent that the three elements have practically no independent existence.

Of all the minerals the pyroxene shows the least tendency towards intergrowth with the others. Vesuvianite, microperthite, anorthite, and scapolite derived from anorthite are frequently found as separated but optically continuous fragments. A continuity like this, in the case of the first two minerals, may extend over a considerable area.

(2) *The Coarse-grained Nodules.*

Only one of the coarse-grained nodules is here described in detail as the other, which is the most northerly nodule, closely resembles it. The nodule shows much variability in texture and mineral composition. It may be divided into:—

(*a*) A relatively fine-grained type occupying much of the lower half of the nodule, that is like the type already described apart from the fact that scapolite is far more common than anorthite-calcite-orthoclase symplectite.

(*b*) A type distributed irregularly along the lower margin and sharply defined by a sinuous boundary from (*a*). It is only light greenish yellow in colour owing to the low absorption of the pyroxene. Bytownite, clinozoisite, and prehnite are other characteristic minerals.

(*c*) A type composed essentially of large microperthites, scapolite, and bytownite. It is developed at several points at the margin.

(*d*) A very coarse vesuvianite-scapolite-pyroxene rock; the most common and most conspicuous type. Symplectites are prominent in thin section. Vesuvianite and scapolite may reach the order of an inch or more in size though normally much less.

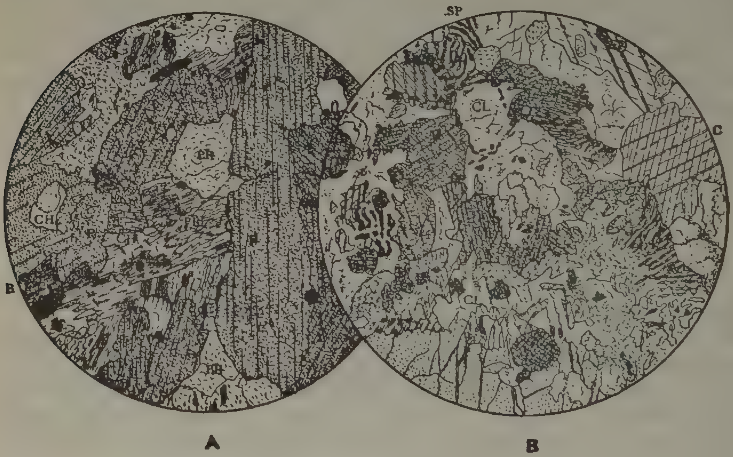
---

[1] The refractive index determinations in this paper are subject to an error of ± 0·002.

The following twenty-four minerals are found in this rock :—

vesuvianite
scapolite (mizzonite)
pink augite
greenish or colourless augite
diopsidic augite
sphene
anorthite
bytownite
calcite
zoisite
clinozoisite
microperthite
orthoclase
biotite
hornblende
prochlorite
prehnite
albite
muscovite
garnet
apatite
black iron ore
pyrrhotite
graphite

(*a*) An analysis of the pyroxene from this rock and some optical properties are on page 464. The data compare fairly closely with a black pyroxene described by Laitakari (1921), which is found among other contact minerals as single crystals in limestone, or in groups at the border between limestone and adjacent rock, especially amphibolite veins.



Text-fig. 3.—A. Type (*a*). Biotite intergrown with prehnite, chlorite, and clinozoisite. Pyroxene, sphene, iron ore, and secondary prehnite make the rest of the rock. Scale × 22. B. Type (*b*). Vesuvianite below is fractured and in process of replacement by clinozoisite, turbid material and some sphene. The symplectite host is clinozoisite and the dactylites pyroxene and sphene, but chiefly sphene when associated with calcite. This symplectite almost certainly was initially derived from the vesuvianite. The section exhibits two kinds and periods of alteration of vesuvianite. Scale × 22.

B = Biotite. P = Pyroxene. CH = Chlorite. PR = Prehnite.
CL = Clinozoisite. SP = Sphene. C = Calcite.

The pyroxene may enclose small, often rounded, biotites, which are pleochroic according to the absorption scheme : Z = chestnut brown, Y = light brown, X = light yellow. They are sometimes split by lenses or strips of prehnite. The pyroxene is sometimes slightly altered to a green hornblende which has X = colourless to pale green, Y = greenish brown, and Z = olive (Y > Z > X). There is little evidence to suggest that biotite is replacing the pyroxene and there is no indication of a relationship between biotite and hornblende.

Characteristically the biotite ($\beta = 1{\cdot}611$) occurs in large tablets rounded marginally and about a millimetre in diameter. It is usually much altered along the cleavages to chlorite, chlorite and clinozoisite or prehnite, together with, in all cases, some granules of sphene and iron ore. It is clear that clinozoisite is replacing chlorite, and prehnite replacing both biotite and chlorite, but all four minerals may be found in parallel intergrowth (Text-fig. 3A).

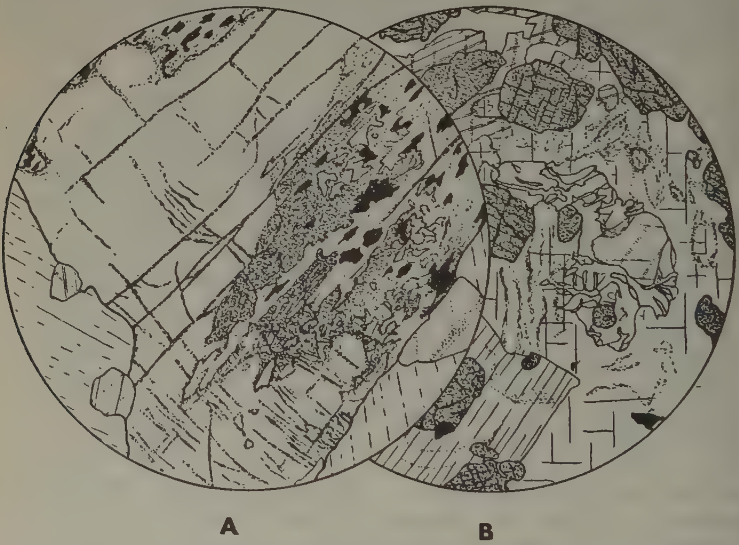
The chlorite is a very pale green variety. It is optically positive, has a birefringence about 0·009 and a refractive index for $\beta = 1{\cdot}614$, data which place it among the aluminous prochlorites according to Winchell's (1933) four-component diagram. Sometimes the prehnite develops to such an extent that only a few shreds or nothing of the chlorite remain. To a certain extent the pseudomorphs so formed are found intergrown in diablastic fashion with the pyroxene. Sometimes this relationship with the pyroxene suggests that the chlorite (or original biotite) has replaced pyroxene.

The clinozoisite developed along the chlorite cleavage may show unevenly distributed second order interference colours indicating the presence of epidote in the molecule. Zoisite is observed as acicular crystals, showing both positive and negative elongation, projecting into basal sections of the chlorite.

A colourless mineral which is biaxial and optically negative has a large optic axial angle and refringence for $\alpha = 1{\cdot}570$ and $\gamma = 1{\cdot}576$. These are the optical properties of bytownite. It is associated with scapolite and replaces it, calcite forming in the same reaction (cf. Text-fig. 4A). The extinction is patchy. The patches often wedge into one another and may be sharply defined. They are due, apparently, to an extremely complex combination of different types of twinning. The bytownite always encloses strings, patches, wedges, and other irregular forms of calcite. It is possibly comparable with the bytownite showing checkered structure observed by Read (1931) in the calc-silicate granulites from the Loch Choire injection complex.

(*b*) The colourless pyroxene has Z : c = 40° and β 1·688, properties which would indicate in the absence of alumina a diopside of an approximate composition $Di_{80}He_{20}$, but its light colour macroscopically and alteration to clinozoisite (Text-fig. 3B) suggest that alumina is present. As subidioblastic crystals it may occur as the sole constituent, but usually, in addition, there are large, irregular, fresh crystals of bytownite with calcite and clinozoisite. Near the contact with type (*a*) turbid albite is associated with clinozoisite and some turbid prehnite. The bytownite is sometimes seen in process of replacement by turbid alteration products composed of prehnite, albite, clinozoisite, and occasionally a little white mica. The clinozoisite, in this type, is very often derived from the pyroxene, which, in numerous cases, has altered to it to some extent. Sphene granules are a conspicuous component in this type owing to their formation as a by-product in replacements of the ferromagnesian minerals. Separating this rock from the wollastonite-garnet hornfels is a narrow zone (1–2 mm.) mainly composed of a mosaic of small microperthites like that surrounding the fine-grained nodule.

(*c*) This type can be regarded as a coarser modification of the microperthite-rich zone. Apart from the minerals already mentioned, pavement-structured areas of calcite occur and graphite is sometimes conspicuous.



TEXT-FIG. 4.—A. Type (*c*). Large scapolite breaking down along cleavages and fractures to bytownite and calcite. Between crossed nicols the bytownite extinguishes as illustrated. Note large microperthites. Scale × 33. B. Type (*d*). Anorthite-calcite-orthoclase symplectite within a large scapolite. Scale × 33.

That the bytownite-calcite association is a replacement product of scapolite is confirmed by the presence of pseudomorphs, of this association, after scapolite showing the forms (100) and (110). These pseudomorphs are the only indication of idioblastic scapolite. They are embedded in large microperthites.

The microperthite is always fresh. Very often the included droplets of plagioclase are in patches and almost always a narrow orthoclase zone clear of them is in contact with the other minerals. Uneven extinction is usual in the larger crystals. Vesuvianite in fairly large crystals may be isolated in this rock.

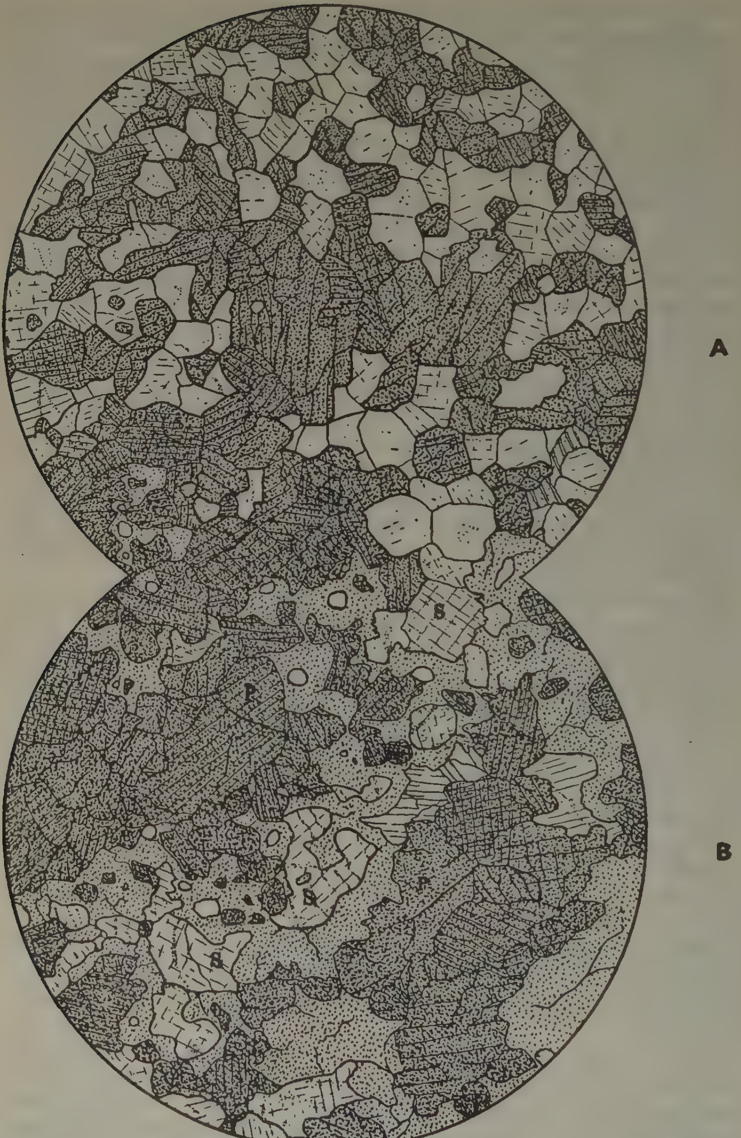
(*d*) An analysis of vesuvianite will be found on page 463. The clear, dark brown, crystals of the hand specimen are only pale yellow microscopically, the colour occasionally showing a slightly uneven intensity in different parts of the same crystal, corresponding to a difference in birefringence, there being highest birefringence where there is greatest depth of colour. The mineral is optically negative and uniaxial, shows little sign of cleavage or pleochroism and no crystal faces. It may contain a large number of small apatite inclusions and is always poeciloblastic with respect to pyroxene and sometimes scapolite or calcite.

With the vesuvianite, very often, vermiform intergrowths are linked in a way that indicates their derivation at its expense, for in very many cases dactylites are orientated normal to its surface and frequently occur as rosettes or cabbage-shaped bunches with their convex side forming an embayment in the parent crystal (Text-fig. 6A, B). In this or in other ways vesuvianite is found in contact with a symplectite but never encloses it. In some cases the symplectite might be considered as synantetic between vesuvianite and scapolite (Text-fig. 6A) but in others (Text-fig. 6B) such a relationship does not exist.

Sometimes isolated fragments of nearly similar sizes or of very great extremes in sizes are spread throughout the section, yet there is uniform extinction; or the vesuvianite may form an evenly extinguishing ground for the pyroxenes and scapolites (Text-fig. 5B). This latter relationship suggests that the vesuvianite may have grown at the expense of the pyroxene and scapolite along their line of contact, and it is a point in favour of this view that the pyroxenes and scapolites enclosed in vesuvianite tend to be smaller and rounder than elsewhere.

The pyroxene is unevenly pink, greenish, or colourless. The refractive indices of the microscopically greenish to colourless varieties are slightly lower than the pink variety, but the extinction angle is not appreciably different. Well-developed prisms may be as much as eight times as long as broad. In a few cases the mineral has become partly replaced by clinozoisite, and where this has taken place, iron ore and sphene are common indicating a probable paragenesis.

Where the pyroxene dactylites in the symplectite have undergone a dark turbid alteration, which is of common occurrence, some of the larger pyroxenes may be similarly altered, and it is sometimes apparent that the alteration is confined to the pink areas in individual pyroxenes. Such crystals still show even extinction underneath the sooty material as if the alteration was of submicroscopic inclusions rather than of the mineral itself. The turbid or sooty material has the appearance of leucoxene and this together with its association with pink pyroxene and sphene suggests that it is leucoxene.



Text-fig. 5.—A. Pflaster arrangement of pyroxenes and scapolites with interstitial vesuvianite near the junction with B. B. Vesuvianite enclosing pyroxene and scapolite. Practically all the vesuvianite extinguishes as one individual. Scale × 30. The drawing is of a slice from the most northerly coarse-grained nodule wherein this particular relationship is well displayed. P = Pyroxene. S = Scapolite.

Sphene may occur as small rounded granules, as occasional wedge or lozenge-shaped sections set in scapolite or as large, shapeless crystals moulded on the pyroxenes. The invariable association of altered symplectite with this mineral is very noticeable, and sometimes sphene is found almost exclusively in the reaction zone of vesuvianite. Vesuvianite never encloses sphene.

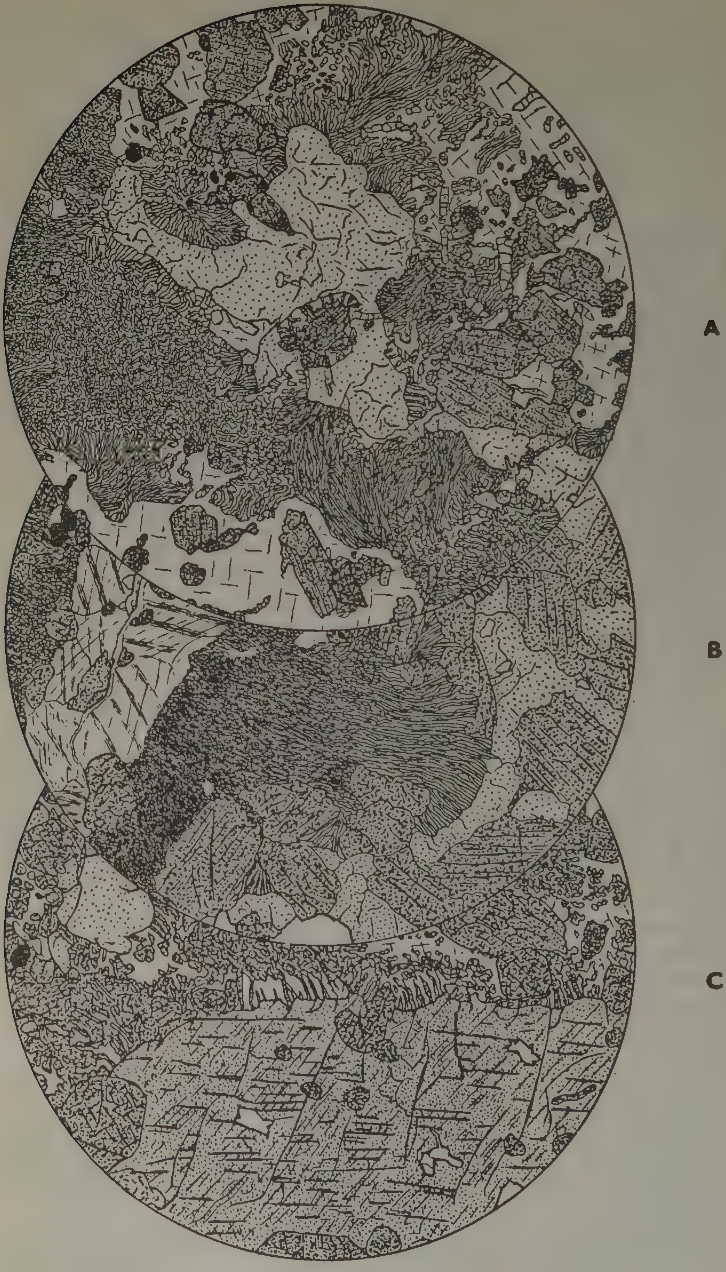
The refractive indices of the scapolite are $\omega = 1{\cdot}586$, $\epsilon = 1{\cdot}555$ ($\omega - \epsilon = 0{\cdot}031$). This calculated value of the birefringence should correspond with a specific gravity of 2·72 or a maximum of 2·75 if the possible error (0·004) in the birefringence is taken into account. The observed specific gravity was 2·76. This indicates an approximate composition $Ma_{23}Me_{77}$, corresponding fairly accurately with the ratio $Ab_{20}An_{80}$ of the derived bytownite ($\beta = 1{\cdot}571$). Some grains of scapolite were fused with sodium carbonate, the fused material then being dissolved in nitric acid. The solution so obtained, on the addition of silver nitrate, gave rise to a thin white precipitate indicating the presence of a small proportion of the chlormarialite molecule in the original scapolite. The scapolite shows no crystal outlines and usually builds large poeciloblastic crystals enclosing other minerals. Smaller ones may, collectively, exhibit pflaster arrangement. A fibrous alteration product may form along the rectangular cleavage but often the mineral is quite fresh and may occur like this in a section which, by containing much leucoxene, gives the impression of an advanced state of alteration of the rock. Occasionally the scapolite contains a number of apatite inclusions.

Only one hornblende crystal (1 cm. by 7 mm.) could be found. It is optically negative and pleochroic according to the scheme, Y = olive with a brown tinge $\geqslant$ Z = olive with a yellow tinge $>$ X = pale yellowish green. It is riddled with shapeless, rounded, or, rarely, idioblastic, pyroxenes, and apatite is also enclosed. Where there is more pyroxene than hornblende this mineral forms, like vesuvianite, an evenly extinguishing area of interstitial scraps. The relationships, in general, are like those of vesuvianite. At one place the hornblende (Text-fig. 6c) appears to give rise to a scapolite-pyroxene symplectite, but as this is only found in this one place (although it was possible to cut three differently orientated sections of the mineral) the validity of the reaction, so indicated, is uncertain. The symplectite may have been derived from vesuvianite.

In addition to many other forms that calcite may take it is found as peociloblastic crystals enclosing pyroxenes.

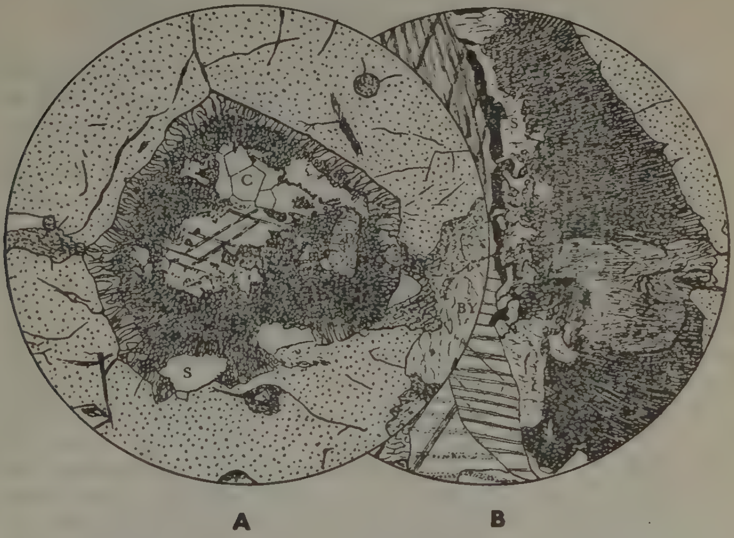
Microperthite may form an evenly extinguishing ground for pyroxenes. Only where microperthite is present is the anorthite-calcite-orthoclase symplectite (Text-fig. 4B) found in this type. It is associated with calcite and may be partly replaced by scapolite. It is probable that this symplectite owes its formation to a reaction between microperthite and calcite.

Clinozoisite is formed as small granules or larger irregular crystals. The characteristic associations are with pyroxene, symplectite,



TEXT-FIG. 6.

vesuvianite, and with iron ore and sphene. Between crossed nicols an interesting occurrence is as thin streaks of anomalous blues and yellows ramifying intricately throughout a large vesuvianite yet extinguishing evenly and independently of it. This replacement of vesuvianite along intersecting cracks may proceed to a stage where angular fragments of a single large vesuvianite are left stranded in a large crystal of clinozoisite.



Text-fig. 7.—A. Type (*d*). Symplectite of pyroxene and scapolite surrounding calcite and enclosed in a large vesuvianite. The boundary of the symplectite towards the vesuvianite is six-sided, recalling sections of dodecahedral garnet. The symplectite is turbid with leucoxene. Scale × 33. B. The same crystal of vesuvianite as in A giving rise marginally to the same symplectite with leucoxene. At one place, clearly bounded, the pyroxene dactylites are thinner and there is no leucoxene. The structure suggests a pseudomorph after garnet. Isotropic garnet, within the " pseudomorph " and between scapolite and calcite, is represented in black. Scale × 33.
S = Scapolite. C = Calcite. P = Pyroxene. BY = Bytownite (after scapolite).

Text-fig. 6.—A. Large residual crystal of vesuvianite surrounded by scapolite—pyroxene symplectite and large scapolites. Pyroxene, sphene, apatite, and ore are also present. Scale × 20. B. Remnants of vesuvianite, separated but in optical continuity, which have been left after replacement of a large vesuvianite by the scapolite-pyroxene symplectite. Calcite, pyroxene, and a little sphene and ore compose the rest of the section. Scale × 25. C. A large hornblende associated with a symplectite of scapolite and pyroxene. On the left are scrappy portions of a vesuvianite the largest of which is breaking down to a scapolite-pyroxene symplectite. Larger pyroxenes, and a little sphene and ore are the other minerals. Scale × 25.

Types (*c*) and (*d*) of the coarse-grained nodule already described are represented in the most northerly nodule. The other two types have not been found. A different type, which may be called type (*e*), contains wollastonite together with a considerable amount of garnet. This type links up this nodule with the small nodules in which wollastonite and garnet are conspicuous and essential minerals. It is sometimes clear that garnet replaces scapolite.

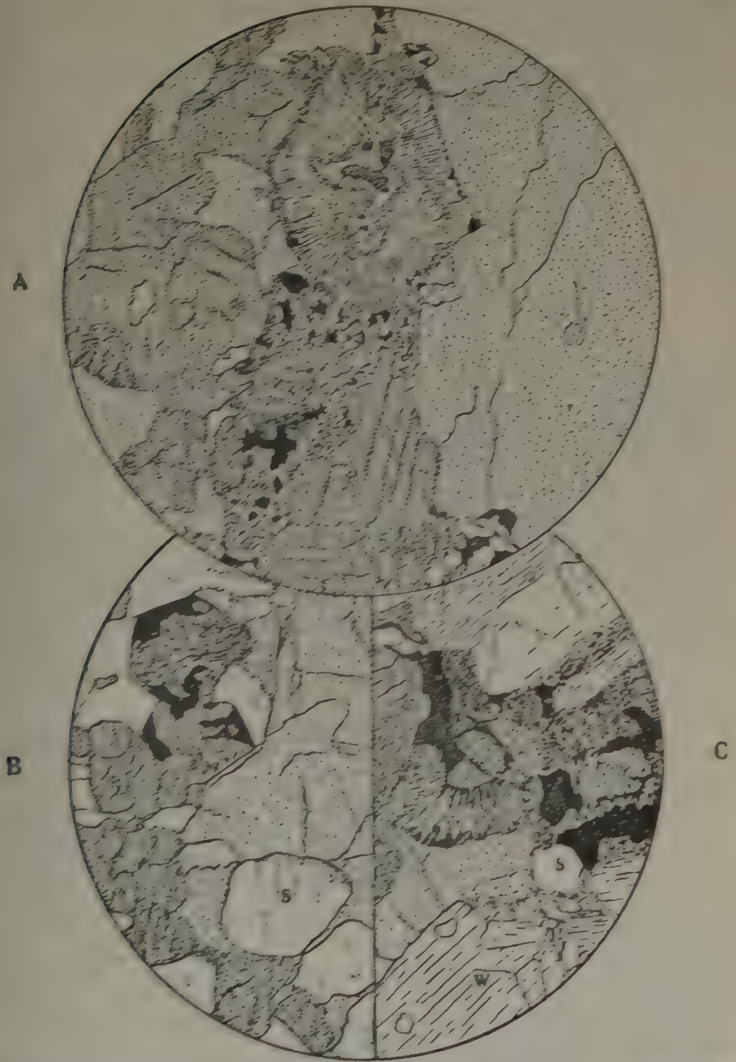
(3) *The Small Nodules.*

In the small nodules the characteristic mineral assemblage is vesuvianite, wollastonite, garnet, microperthite, scapolite, and to a lesser extent pink augite and calcite. These nodules, therefore, differ from the surrounding rock by containing large vesuvianites, highly poeciloblastic or as an evenly extinguishing, interstitial ground surrounding, in both cases, augite, scapolite, and calcite as rounded relics, and also wollastonite. Symplectites derived from vesuvianite and garnet are often conspicuous and it is a remarkable feature than in the normal rock surrounding the nodules the garnet shows no evidence of instability. The garnet is found as a thin, ramifying, network along the contacts of almost any two adjacent minerals, or crystals of the same mineral. Commonly, however, it arises between calcite and scapolite. The garnet in the second coarse-grained nodule has the same habit. The vesuvianite may also form an intergranular network and it again is not restricted to the contacts of any two particular minerals such as pyroxene and scapolite. It seems clear that in the case of the formation of both garnet and vesuvianite there has been some migration of material, particularly CaO and SiO_2, within the rock. The garnet may also be irregular, poeciloblastic, or idioblastic (Text-fig. 8B). The wollastonite ($\beta = 1{\cdot}631$) occurs in stout laths which may be sub-parallel. Narrow, colourless selvages of a mineral referred to oligoclase show, rarely, polysynthetic twinning and the refringence is a little above Canada balsam. It often occurs between microperthite and adjacent minerals and sometimes between two minerals other than microperthite. Sometimes the microperthite is the dominating component.

A small nodule was discovered also, which closely resembles type (*b*). Clinozoisite is the most conspicuous component. It is associated with a macroscopically light green pyroxene which is intergrown with prochlorite. Turbid albite, a little sphene, and prehnite are also observed.

(4) *Symplectites.*

The line between what is properly a symplectite (Sederholm, 1916) and what is simply an intergrowth is possibly a little arbitrary. Here the term includes all those intergrowths wherein one at least of the elements assumes a vermicular or myrmekitic form. On this



Text-fig. 8.—A. Type (*d*). Large vesuvianite associated with a six-sided pseudomorph probably replacing garnet. Isotropic garnet, represented in black, is associated with this pseudomorph, and with decomposed scapolite. Pyroxene and a little apatite, sphene, and calcite are also present. Scale × 50. B. Type (*e*). Vesuvianite associated with idioblastic garnet which is in process of replacement by a symplectite containing (as in A) thin pyroxene dactylites. Isotropic garnet is represented in black. Scale × 50. C. Type (*e*). Irregular garnet breaking down as in B. Wollastonite is present in this section. Scale × 50.

P = Pyroxene. S = Scapolite. W = Wollastonite.

basis the following symplectites may be found. The first mineral in each case is the host.

(1) anorthite-(titaniferous) pyroxene-calcite.
(2) anorthite-(titaniferous) pyroxene.
(3) scapolite-(titaniferous) pyroxene.
(4) clinozoisite-(titaniferous) pyroxene.
(5) clinozoisite-pyroxene-sphene.
(6) clinozoisite-sphene.

These six are all primarily derived from vesuvianite.

(7) (scapolite)-pyroxene-garnet.
(8). anorthite-calcite-orthoclase.
(9) anorthite-calcite.
(10) scapolite-calcite.

Symplectites (1) and (2) are rare, and (3) is by far the most common type. The scapolite host is usually continuous with one or other of the larger scapolites of the rock (Text-fig. 6A), and a number of dactylites extinguish as one individual. The dactylites may be optically continuous with a neighbouring pyroxene, but, generally, they are associated with differently orientated crystals. Laitakari (1921) has found a similar symplectite composed of basic plagioclase and pyroxene replacing a parallel intergrowth of vesuvianite and garnet. The common type of symplectite is prone to alteration with the production of leucoxene but the change is unconnected, as noted before, with any secondary alteration of the rock. The change seems sometimes to be related to the presence of calcite (Text-fig. 7A, B).

When clinozoisite appears within the symplectite this structure tends to lose its characteristic form, as clinozoisite is capable of replacing both components, but dactylitic remnants remain embedded in it. Where this takes place sphene is prominent and may arise in dactylitic form. It does not appear normally to form directly from vesuvianite at the period when the scapolite-pyroxene symplectite is formed, but to remain potentially within the pyroxene. Judging by the high percentage of TiO_2 in the vesuvianite it appears that if little or none is lost in the reaction producing symplectite the colourless pyroxene-dactylites should contain a high TiO_2 percentage. Hence, possibly, the ease with which they give rise to leucoxene. The pyroxene is especially sensitive to an environment in which sphene is easily formed.

The scapolite of the symplectite derived from garnet is not always distinguishable. This symplectite differs from that derived from vesuvianite in the delicate character of the dactylites, the absence of leucoxene, and the almost invariable presence of relic threads of garnet within the symplectite (Text-figs. 7B, 8A, B). In Text-fig. 7A the dactylites are dark with leucoxene. This is not so in Text-fig. 8A. In both these cases the six-sided structure encloses, centrally, calcite associated with sphene.

3. CHEMICAL ANALYSES.

Vesuvianite.	*%*	*Mol. Props.*		*A. Metal atoms on a basis of 38 (O, OH, F).*				*B. Metal atoms on a basis of 76 (O, OH, F).*
SiO_2	36·53	·609	Z	8·84		9		
Al_2O_3	15·79	·155		4·50	·16 ·340	4	Z	18
Fe_2O_3	2·05	·013		·378				
FeO	2·11	·029	Y	·421		2·26	Y	13·53
TiO_2	3·75	·047		·682				
MgO	2·61	·065		·944	·439 ·505			
CaO	35·70	·637		9·249				
MnO	0·11	·001	X	·014		10	X	18·99
Na_2O	0·38	·006		·174				
K_2O	0·21	·002		·058				
H_2O +	0·60	·033		·958	1·77			3·54
F_2	1·08	·028		·813				
H_2O −	0·10							
P_2O_5	0·00							
CO_2	0·00							
	101·02							
$- O = F_2 =$	0·58							
	100·44							

A. According to the structural formula (1931) :—
$Ca_{10}Al_4(MgFe)_2Si_9O_{34}(OH)_4$.
B. According to Machatschki's (1930) formula :—
$Ca_{19}(MgAl)_{13}Si_{18}O_{72}(OH)_4$.
Analyst.—N. Sahlbom.

$\omega = 1{\cdot}724$, $\epsilon = 1{\cdot}715$, $\omega - \epsilon = {\cdot}009$, Sp. gr. = 3·42.

The vesuvianite shows a fairly close agreement with the formula established on X-ray data.

Of the twenty-two analyses listed in Machatschki's paper only one shows so high a figure in the Y group. The excess in the Y group, referred to Machatschki's formula, is almost equal to the deficiency in the (OH, F) group. It is a common feature of vesuvianites that they show considerable elasticity in the quantity of (OH, F) atoms. As far as could be ascertained no single vesuvianite yet described contains at the same time so much titanium and fluorine; the titanium is in unusual amount. Only pyrogenetic vesuvianites appear to contain so much or more titanium. The optical properties are normal. The specific gravity is near that of the Tennberg (1923) vesuvianite which is 3·417. Both values are relatively high.

	Pink pyroxene. %	*Mol. props.*	*Metal atoms on a basis 6(O, OH).*		
SiO_2	46·32	·771	1·759		2
Al_2O_3	6·51	·064	·292	·241	
				·051	·994
Fe_2O_3	1·48	·009	·042		
FeO	8·45	·118	·269		
MgO	10·45	·260	·593		
TiO_2	1·20	·015	·034		
MnO	0·15	·002	·005		
CaO	24·10	·430	·981		1·003
Na_2O	0·31	·005	·022		
K_2O	0·59	·006	·028		
H_2O+	0·34	·019	·086		
H_2O-	0·12				
	100·02				

Analyst.—N. Sahlbom.

$\alpha = 1{\cdot}694$ = greenish to colourless.
$\beta = 1{\cdot}699$ = pink to pinkish brown.
$\gamma = 1{\cdot}721$ = greenish to colourless.
$\gamma - \alpha = {\cdot}027$, $\gamma : c = 43{\cdot}5°$, $(+)2V = 59°$, Sp. gr. = 3·42.

Strong inclined dispersion ($\rho > v$) and very strong in the case of the optic axis nearest c. Simple twinning on 100 is rare.

The mineral shows a close agreement with the structural formula (Warren and Bragg, 1929). The optical properties, specific gravity, and chemical composition compare fairly closely with the pyroxene from Ersby, Finland (Laitakari, 1921), which differs chiefly in its lower alumina and titanium dioxide and higher iron oxide percentages. In both cases the affinity is with the pyrogenetic augites.

The pyroxene from Ardgour is comparable with the titan-augites in respect of chemical composition and strong dispersion. The titanium content is lower than normal. Apart from this anomaly it might be called a lime-rich titan-augite. That the colour is due to titanium is emphasized by the concentration, occasionally, of leucoxene in the pink areas of unevenly coloured crystals. The analysed mineral was of almost uniformly coloured crystals. This augite, therefore, must be regarded, owing to its colour, as an unusual, if not distinctive, type.

4. THE ORIGIN OF THE NODULES AND THE PHYSICAL CONDITIONS CONTROLLING THEIR METAMORPHISM.

In the main exposure of marble in the Coire na Muc all stages may be seen between flat-folded sediments embedded in a thick bed of practically pure marble to scattered remains of these folded sediments which have been torn apart, sometimes rounded, and dispersed. Such fragments may show a similar aggregate of augite associated with wollastonite-rich rock. Until further evidence is available a similar phenomenon most adequately explains the character and relationships of the nodules which have been here described. It is accordingly suggested that the nodules represent the remains of hard bands of impure calcareous sedimentary rock.

Temperatures of a rather exceptionally high order are indicated by the following facts. In the production of the extensive hybridization at the contact with the diorite much heat, among other things, must have been required, owing to the endothermal nature of the principal reactions involved. Other well-established high-temperature phenomena are the occurrence of stout wollastonite laths and microperthite (Eskola, 1922). Consistent with such conditions the vesuvianite and augite have pyrogenetic affinities.

Structurally the rocks have much in common with metasomatic or hybrid types. Such features as the extreme variability in the texture and mineral composition, the highly poeciloblastic or sieve structures, and the symplectitic and other complex intergrowths are all far more characteristic of these types than of any others. Pavement structure is not unknown in hybrids, although in general more typically and simply the result of contact action. Thus metasomatic processes, though often leading to crystallization in a solid rock, give rise to structures distinct from the results of normal crystalloblastic crystallization. Symplectites, also, are commonly formed as late or secondary products in magmatic rocks.

5. MINERAL REPLACEMENTS.

These replacements may be summarized as follows :—

A
augite, scapolite, etc., by vesuvianite.
augite, scapolite, etc., by garnet.

B
vesuvianite by scapolite-(titaniferous) pyroxene symplectite.
garnet by scapolite-pyroxene symplectite.
calcite by anorthite-calcite-orthoclase symplectite.
anorthite-calcite-orthoclase symplectite by scapolite.

C
scapolite by bytownite and calcite.
bytownite and calcite by clinozoisite.
titaniferous augite by secondary hornblende.
(augite by biotite).
biotite by chlorite, prehnite, clinozoisite, sphene, and iron ore.
pyroxenes and vesuvianite by clinozoisite, sphene, and iron ore.
titaniferous pyroxene-scapolite symplectite by clinozoisite, sphene, and iron ore.

A, B, and C represent, in a generalized way, three consecutive stages in the metamorphic history of these nodules.

It may be inferred with a fair degree of certainty that the mineral composition of the nodules prior to stage A was essentially pyroxene microperthite and calcite or with wollastonite, in addition in the less aluminous types. Some scapolite may also have been present. These mineral assemblages may have been formed during the initial stages of the magmatic intrusion. During continued high temperature conditions due to this intrusion the introduction of such volatiles as H_2O, F_2, Cl_2, and phosphorus compounds from the magma must have led to a considerable degree of molecular mobility within the nodules and to the migration and segregation of microperthite. Under these conditions augite, scapolite, etc., are partially replaced by vesuvianite or garnet. Both these minerals enclose scapolite which was formed also while the vesuvianite (stage B) was in process of replacement by symplectite. In other words it appears that scapolite has formed or recrystallized through a range of chemical and metamorphic conditions. One way in which the scapolite may have been produced (see p. 457) is by a reaction between microperthite and calcite, although this reaction may be arrested at a stage represented by the anorthite-calcite-orthoclase symplectite. Apatite was probably formed during stage A.

The nodules appear to have acted as a trap for volatiles and to owe much of their heterogeneity and structural peculiarities to their influence.

Pyroxene and scapolite may be found in contact with one another (Text-fig. 5A) without any sign of reaction along their line of contact. Migration of lime and silica along the contacts of the mineral grains in the presence of volatiles, or, possibly, in actual solution in the volatiles, has led to the formation of vesuvianite at their expense and, in particular at the expense of pyroxene and scapolite. Later, when the volatiles became fixed or less active, the re-establishment of conditions in which pyroxene and scapolite are stable caused the complex vesuvianite molecules to break up and give rise simultaneously to scapolite and pyroxene. These changes may be represented as follows :—

$$\underset{\text{augite}}{2[CaMg(SiO_3)_2].CaAl_2SiO_6} + \underset{\text{anorthite}}{Ca(Al_2Si_2O_8)} + 6CaCO_3 + 2SiO_2 + 2H_2O$$

$$\rightleftarrows \underset{\text{vesuvianite.}}{Ca_{10}Al_4Mg_2Si_9O_{34}(OH)_4} + 6CO_2$$

A similar change occurs in the case of the formation and breaking up of garnet.

Mineral replacements in group C are retrogressive under waning temperature.

6. CHEMICAL INTERCHANGE DURING THE MINERAL REPLACEMENTS.

CaO, SiO_2, F_2, and H_2O are required in the formation of vesuvianite from augite and scapolite. The same oxides without the addition of volatiles are necessary for the production of garnet. The reversal of these reactions, when the scapolite-pyroxene symplectite was formed, involves a loss of the substances introduced during the formation of vesuvianite and garnet. In the retrogressive period of metamorphism vesuvianite breaks down, with a loss of MgO to clinozoisite and sphene. The fate of the MgO is not known. No dolomite has been detected in the nodules. Augite by addition of silica, lime, and water gives rise to clinozoisite, iron ore, and sphene. By addition of H_2O biotite is replaced by chlorite with the release of K_2O and TiO_2, the latter joining with calcite to form sphene. The chlorite is itself replaced by clinozoisite or prehnite and iron ore. This entails the addition of CaO and a loss of MgO. The biotite may, apparently, pass directly to prehnite, sphene, and iron ore.

The conversion of scapolite to bytownite intergrown with calcite involves the loss of sodium chloride or carbonate, the fate of which is unknown. In the presence of H_2O, clinozoisite arises at the expense of this intergrowth or, if silica is available, albite and prehnite are the products.

7. Summary and Conclusions.

The nodules examined have been shown to contain a variety of minerals and to exhibit certain mineralogical and structural differences from one another or within the nodules themselves. The mineralogical differences serve to separate five definite types of mineral facies. There are also described types transitional between the nodules themselves, and between them and the surrounding rock, grading from types sufficiently aluminous to exclude the formation of wollastonite to less aluminous types in which this mineral is formed.

Owing to insufficiently prolonged variations of the metamorphic conditions equilibrium has not been established, and a remarkable series of replacement structures has been left in the rock by means of which the course of several stages of its metamorphism has been established.

Lack of knowledge concerning the metamorphic conditions previous to changes due to the influence of the surrounding diorite, the isolated character of the nodules and the intricacy of the relationships between the minerals render the origin and metamorphism of these nodules subject to a variety of interpretations. The balance of evidence seems in favour of the one put forward here.

8. Acknowledgments.

The research work in Ardgour, from which this is an extract, has been carried out with the aid of a Vans Dunlop Scholarship and the Falconer Memorial Fellowship, both from Edinburgh University. The writer is very grateful to Professor T. J. Jehu for his encouragement and to Professor C. E. Tilley for a great deal of help and advice.

9. References.

Bailey, E. B., and Maufe, H. B. (1916). "The Geology of Ben Nevis and Glencoe" (Explanation of Sheet 53), *Mem. Geol. Survey of Scotland*, p. 84.

Sederholm, J. J. (1916). "On Synantetic Minerals and Related Phenomena," *Bull. Comm. Géol. Finlande*, No. 48.

Laitakari, A. (1921). "Petrographie und Mineralogie der Kalksteinlagerstätten von Parainen (Pargas)," *Bull. Comm. Géol. Finlande*, No. 54.

Eckermann, H. von (1922). "Rocks and Minerals of the Mansjö Mt.," *Géol. Fören. Stockholm Förhandl.*, lxiv, p. 330.
—— (1923). "Rocks and Contact Minerals of Tennberg," ibid., xlv, p. 490.
Eskola, P. (1915). "On the Relations between the Chemical and Mineralogical Composition in the Metamorphic Rocks of the Orijärvi Region," *Bull. Comm. Géol. Finlande*, No. 44, p. 144.
—— (1922). "On Contact Phenomena between Gneiss and Limestone in Western Massachusetts," *Jour. of Geol.*, xxx, No. 4, p. 292.
Warren, B., and Bragg, W. L. (1929). "The Structure of Diopside, CaMg $(SiO_3)_2$," *Zeits. für Krist.*, lxix, p. 168.
Machatschki, F. (1930). "Die Summenformel des Vesuvians und seine Beziehungen zum Granat," *Centralblatt für Mineralogie*, p. 284.
Read, H. H. (1931). "The Geology of Central Sutherland," *Mem. Geol. Surv. Scotland*, p. 132.
Warren, B., and Modell, D. I. (1931). "The Structure of Vesuvianite, $Ca_{10}Al_4(MgFe)_2Si_9O_{34}(OH)_4$," *Zeits. für Krist.*, lxxviii, p. 422.
Winchell, A. N. (1933). *Elements of Optical Mineralogy*, part ii, p. 278.

The Stratigraphical Order of the Dalradian Rocks of the Banffshire Coast

By H. H. Read, University of Liverpool.

(PLATE XIII.)

Introduction.

In the investigation of the somewhat poorly exposed Dalradian rocks of North-East Scotland, the Banffshire coast-section is of inestimable value. Excellent exposures are presented for study throughout a dip-section some 25 miles in length. The general characters, subdivisions, and relationships of the Dalradian rocks of this section were dealt with by me (1, 2, 3)[1] before the importance of current-bedding and graded bedding in the investigation of the stratigraphical order of metamorphic rocks had been realized. In this paper an account is given of the examination of the section along the lines developed by Professor E. B. Bailey and the Glasgow school (5, 6, 7, 8, 9). I have to thank especially Professor Bailey and Dr. W. J. McCallien for their instruction in the study of current-bedding in metamorphic rocks during excursions to the Kinlochleven and Schichallion districts.

The study of the Banffshire coast-section from this point of view has yielded very encouraging results, which will be of value for further work in North-East Scotland, since the stratigraphical order can be demonstrated with some certainty. Further, observations here given on the possibility of detecting graded bedding in sediments completely recrystallized under certain conditions of metamorphism may be, in my opinion, of more general application.

---

[1] Numbers within parentheses refer to the List of References at the end of this paper.

The Banffshire Coast-Section of the Dalradian.

The subdivisions of the Dalradian rocks of the coast-section (Fig. 1) are shown below :—

Banff Division
- *n* Macduff Slates and Pebbly Grits.
- *m* Boyndie Bay Andalusite-schists and Pebbly Grits.
- *l* Whitehills Group.
- *k* Boyne Limestone.

(The *Boyne Line*; a line of discontinuity along which various members of the Banff and Keith divisions come into conjunction.)

Keith Division
- *j* Cowhythe Gneiss.
- *h* Portsoy Group.
- *g* Durn Hill Quartzite.
- *f* Sandend Black Schist and Limestone Group.
- *e* Garron Point Actinolitic Schists.
- *d* Crathie Point Calcareous Flags.
- *c* Findlater Flags.
- *b* West Sands Garnetiferous Mica-schists.
- *a* Cullen Quartzite
  - a_2—Logie Head Beds, flaggy.
  - a_1—Findochty Beds, massive.

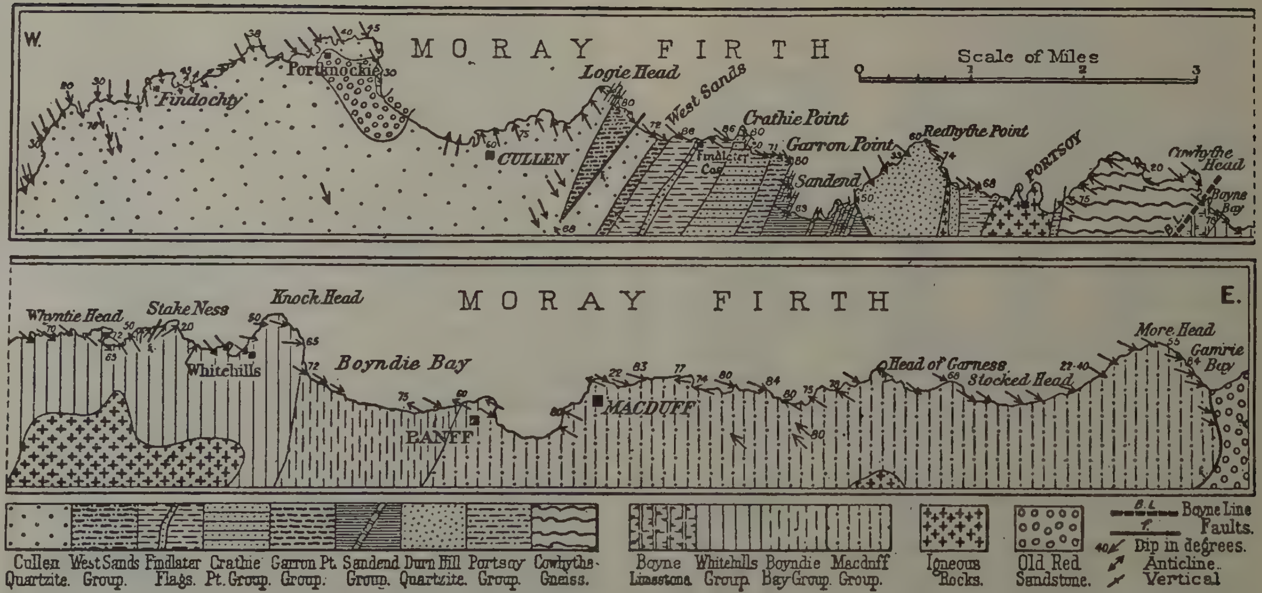
Observations connected with the determination of the stratigraphical order show that the Keith Division is characterized by current-bedding and the Banff Division by graded bedding. The two divisions are now treated separately.

Current-Bedding in the Keith Division.

In this description a beginning is made at the western end of the section at the Cullen Quartzite and the remaining groups treated in order eastwards to the Cowhythe Gneiss.

Current-bedding can be detected practically everywhere in the 5-mile-long coast-section of the *Cullen Quartzite*. The medium-grained granulitic quartzite, the dominant rock of this group, is composed almost entirely of quartz grains, with a small quantity of felspar and mica ; the grains show sutured edges, and the rock is completely recrystallized. This pinkish or whitish rock is streaked with dark layers, 1–2 mm. wide, which weather rusty. The dark layers consist of a concentration of biotite flakes, in which occur abundant zircon, garnet, epidote, and iron ore. For example, in a traverse 2 cm. long of such a dark band there were 5 zircon, 13 garnet, 2 epidote, and 30 ore grains ; in a comparable traverse through the whitish quartzite, 1 zircon and 2 ore grains only were encountered. How much of these constituents of the dark bands is recrystallized does not affect the conclusion that they are of pay-streak character, and represent original sedimentary structures. Viewed in three dimensions, these layers show the characters of current-bedding. Asymptotic bottoms and truncated tops are everywhere observed, and the dark bands form always the bottom plane of a truncating bed.

A selection of the observations in the Cullen Quartzite is now given. Along the coast south-west of Findochty, the quartzite dips



TEXT-FIG. 1.—Geological Map of the Banffshire Coast. (Note: The dips to the north-north-west between Cullen and Logie Head are reversed, as explained in the text.) Reproduced by permission of the Controller of H.M. Stationery Office from "The Geology of the Country around Banff, etc.," *Mem. Gecl. Surv. Scotland,* Explan. Sheets 86 and 96, 1923.

south-east at moderate angles, and the current-bedding shows consistently that the younger beds come on towards the same direction. The upfolds and downfolds excellently seen just west of Findochty and between Findochty and Portknockie are found to be anticlines and synclines respectively; the axes of the folds pitch east-north-east. Dozens of examples of current-bedding are seen at Portknockie around the harbour and eastwards to the outcrop of the Old Red Sandstone of Cullen Bay. An excellent but rather insalubrious group of exposures is found at the spot where the town refuse is dumped over the cliff. The quartzite north-east of Cullen towards Logie Head is inverted; the structural dips are towards the north-west at high angles, as shown in Fig. 1, but current-bedding observations at numerous points show that the stratigraphical order is towards the south-east. The vertical beds of Logie Head provide innumerable examples indicating younger beds towards the south-east. At Logie Head a small faulted area of the West Sands Group intervenes (see Fig. 1); the garnetiferous mica-schists of this group are too argillaceous in character, and the associated flags (? Findlater Flags) found towards the fault limiting the group on the east are too thinly bedded to reveal current-bedding. The strip of Cullen Quartzite next encountered towards the east shows good current-bedding at three localities and these indicate younger beds towards the south-east. The conclusions from these observations in the Cullen Quartzite are therefore that this quartzite is older than the West Sands Group, that its small-scale folds are uninverted, and that the steep north-westerly dips east of Cullen are reversed dips.

In the *West Sands Group* in West Sands, a solitary observation in a siliceous bed in the garnetiferous mica-schists shows current-bedding indicating younger beds towards the south-east.

The succeeding *Findlater Flags* of Findlater Castle are too thinly bedded to show current-bedding, but the vertical *Findlater Castle Quartzite* exposed at the castle itself provides evidence showing that its south-eastern edge is the younger. The *Crathie Point* and *Garron Point* groups of calcareous and actinolitic schists yield no evidence. The same applies to most of the *Sandend Group* of limestones and black schists. Certain observations in the banded limestone on the east side of Sandend Bay may indicate an upward succession towards the south-east, but here there has been so much flowage in the calcareous rocks that the observation is probably of little value. The *Durn Hill Quartzite* of Redhythe Point is disappointing; the quartzite is immensely moved, and boudinage-structure, crushing, and fracturing are ubiquitous. Though colour-banding is occasionally seen, no reliable indications of the stratigraphical order were found, nor are any likely to result from a more extended search. Possibly inland exposures, such as those on Durn Hill itself and farther south, may yield results of value. In the *Portsoy Group*, a quartzose band east of the Marble Quarry

Serpentine (2, Fig. 4) shows current-bedding indicating an upward succession towards the south-east. The remaining group of the Keith Division, the *Cowhythe Gneiss,* is a very coarse oligoclase-biotite-gneiss and provides no evidence of current-bedding.

Results from the Keith Division.

In summary, then, observations on current-bedding in the Keith Division show that the Cullen Quartzite, West Sands Group, Findlater Castle Quartzite, possibly the Sandend Group and the Portsoy Group, constantly show the younger beds towards the south-east. It can be concluded with confidence that the stratigraphical order in this division begins with the Cullen Quartzite at the bottom and ends with the Cowhythe Gneiss at the top.

OBSERVATIONS ON GRADED BEDDING IN THE BANFF DIVISION.

As a result of this present and several previous re-examinations of the Banff Division, I must reaffirm my belief in the unity of this division. J. W. Gregory (10) placed the Macduff group of slates and grits in his Lennoxian. "Gregory has clearly drawn his unconformity between Lennoxian and Dalradian at the position where a change in metamorphic grade takes place in a perfectly uniform and united series of argillaceous and gritty rocks. The unity of the Dalradian and the supposed unconformable Lennoxian can be demonstrated in half an hour on the shore at Banff." (Read, 4, p. 23.)

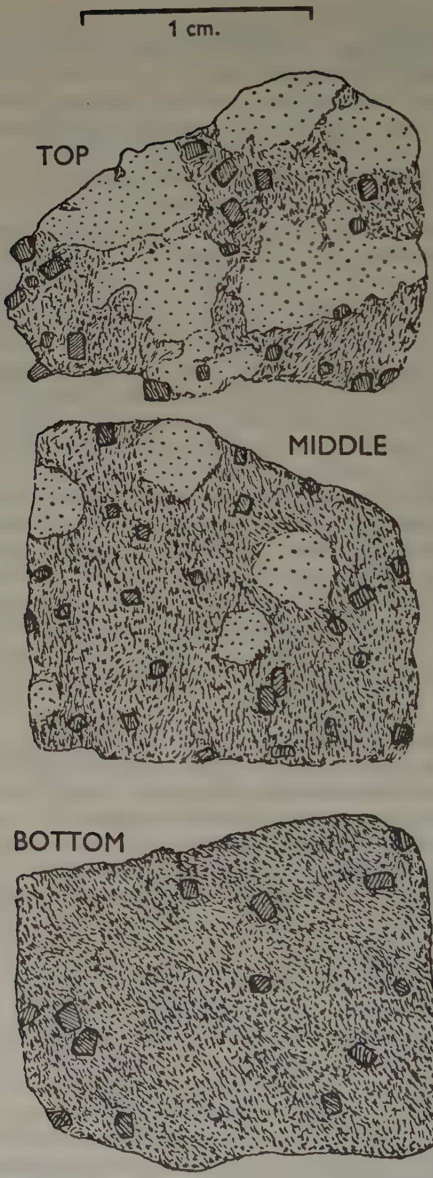
Coming now to the observations on the stratigraphical order in the Banff Division, I have obtained no results from the *Boyne Limestone* and the western part of the *Whitehills Group*; the rocks are intricately folded, mostly very thin-bedded and almost platy. Between Whitehills and Boyndie Bay, however, observations of considerable interest and value have been made.

The rocks of importance in this connection are pebbly grits and andalusite-schists; these are exceptionally well exposed at Whitehills, Knock Head, and in the south-west corner of Boyndie Bay. The *pebbly grits* form beds from 1 foot to 4 or 5 feet in thickness. They are coarse, pebbly rocks, showing large grains, sometimes 1 cm. long, of quartz and felspars in a matrix of fine quartz grains, little felspars, magnetite grains, and much yellow to brown biotite in small laths. In numerous localities, and especially on Knock Head, the grit bands show graded bedding. The structural dip is at fairly high angles to the east and east-south-east, and the grit bands are interbedded in andalusite-schists. It can be observed repeatedly that the western edge of each grit band is coarsely pebbly, and that towards the east in each band the pebbles become finer and that at the east margin of each bed a few crystals of andalusite appear. The change in grain-size and abundance of pebbles takes place perfectly gradually from one side to the other of innumerable grit bands up to 5 feet in thickness. This can be interpreted only as graded bedding, however disquieting the scale may be. The episode of sedimentation of each grit bed began with the deposition of coarse materials, gradually becoming finer till a portion of the clay fraction appeared in the final deposition that closed the episode—on metamorphism, this clay fraction appears as andalusite. All the observations on graded bedding in grits hereabouts point to an upward succession towards the east or east-south-east. Such observations can be made in Whitehills, everywhere around Knock Head, and in Boyndie Bay.

The andalusite-schists provide a very pretty case of graded bedding in totally recrystallized rocks. When the andalusite-schists are examined in detail it is seen that the andalusite is not uniformly distributed in them. I had noted this fact many years ago when I stated "it is at once apparent that the development of andalusite is intimately connected with the nature and composition of the original sediment; the andalusite is often confined to thin beds, often under 1 inch in thickness, interbanded with slightly more siliceous but still somewhat clayey, non-andalusite-bearing phyllites" (2, p. 56).

In innumerable examples the rocks grouped as andalusite-schists are formed of distinct beds, 6 inches to 1 foot in thickness. The west side of each bed shows little or no andalusite; towards the east in each bed, andalusite appears, first as a few crystals, then in greater abundance, till at the east margin of each band the rock is largely composed of granular andalusite. Such a bed is shown in Fig. 1 of Plate XIII, and Fig. 2 of the same plate shows a boulder in which a succession of three beds is clearly seen.

Examination of a series of thin sections cut from different parts of such beds supplies the explanation. The western margins of the beds consist of a medium-grained association of biotite and quartz, with which occur abundant ore-grains, many small euhedral staurolite crystals, and rare tiny garnets and prisms of tourmaline. The eastern margins of the beds show exactly the same association, but in this as a groundmass are set large porphyroblasts of andalusite, up to 1 inch in length, with a few patches of cordierite. In many cases, more than half of the eastern parts of the beds consists of granular andalusite porphyroblasts. Slices cut between the western and eastern margins of beds show intermediate characters—the same groundmass with fewer andalusite porphyroblasts. Rock slices showing the variation are figured in Text-fig. 2. Since the aluminium silicate, andalusite, registers the amount of original clayey material it can be inferred that the amount of this clayey material increased gradually from the western margins of each of these beds towards their eastern margins: that is, each bed is graded from coarse on the west to fine on the east. Further, since the andalusite occurs as large porphyroblasts, the top, which was originally the finest part of the bed, becomes on metamorphism the coarsest-grained portion. It is therefore possible to deduce the stratigraphical order in these totally recrystallized regionally metamorphosed sediments.



Text-fig. 2.—Three sections showing the inferred bottom, middle, and top of an andalusite-schist bed; the bottom shows a few small staurolites in a base of quartz and mica, the middle shows the addition of a few patches of andalusite, and the top shows an abundance of andalusite; note that the quartz-mica-staurolite "groundmass" remains the same throughout the bed.

These observations confirm those made on the graded bedding in the associated pebbly grits, and the inference is that *the Whitehills and Boyndie Bay groups show an upward stratigraphical succession towards the east and east-south-east.*

The margin between the Boyndie Bay and the Macduff groups is marked by the appearance of andalusite spots and their increase in size and number from east to west. Observations on the development of these spots at this margin are of the same kind as those dealing with the andalusite-schists; the spots are more abundant towards the originally more clayey side of individual beds. Numerous observations at this margin show that the general upward stratigraphical succession is towards the east, and that upfolds are anticlines and downfolds synclines. In the *Macduff Group* itself many observations around Banff Harbour and as far as 2 miles to the east of Macduff show that the same is true there.

Results from the Banff Division.

These observations on graded bedding in the Banff Division clearly show that the stratigraphical order is Whitehills Group, Boyndie Bay Group, Macduff Group, and that the last named is the youngest. Since the Boyne Limestone is very firmly linked on to the western edge of the Whitehills Group, the stratigraphical succession in the Banff Division begins with the Boyne Limestone and passes upwards to the Macduff Group.

THE BANFF SYNCLINE.

The existence of a synclinal arrangement of the rocks of the Banff Division has been advanced at various times (2, 3, 4). In the present examination of the stratigraphical order in these rocks I have not gone farther east than a couple of miles beyond Macduff. The results show that up to this point there is an ascending sequence in the Banff Division. The establishment, or not, of the synclinal nature of the Banff Division in the Banff–Turriff area, and of the complementary Buchan anticline farther east, is at present under investigation by Mr. Robert Walls, Beit Research Fellow at the Imperial College, London.

SUMMARY OF RESULTS.

(1) By investigation of current-bedding, the stratigraphical order in the Keith Division is shown to be from Cullen Quartzite upwards to Cowhythe Gneiss.

(2) By investigation of graded bedding the stratigraphical order in the Banff Division is shown to be from Boyne Limestone upwards to Macduff Slates and Grits.

(3) The detection of graded bedding and the establishment of stratigraphical order is shown to be possible in totally recrystallized sediments.

LIST OF REFERENCES.

1. READ, H. H. "The Banffshire Coast Section of the Highland Schists," Sum. Prog. for 1920, *Mem. Geol. Surv. Gt. Brit.*, 1921, 70–80.
2. —— "The Geology of the Country round Banff, Huntly, and Turriff," Explan. Sheets 86 and 96, *Mem. Geol. Surv. Scot.*, 1923.
3. —— "Discussion on Problems of Highland Geology," *Rep. Brit. Assoc.*, Glasgow Meeting, 1929, Sectional Transactions, p. 551.
4. —— "The Grampian Highlands; British Regional Geology," *Geol. Survey*, 1935.
5. BAILEY, E. B. "New Light on Sedimentation and Tectonics," GEOL. MAG., LXVII, 1930, 77.
6. —— "West Highland Tectonics: Loch Leven to Glen Roy," *Q.J.G.S.*, xc, 1934, 462–525.
7. MCCALLIEN, W. J. "The Metamorphic Rocks of Inishowen, Co. Donegal," *Proc. Roy. Irish Acad.*, xlii, Section B, No. 15, 1935, 407–442.
8. ALLISON, A. "The Dalradian Succession in Islay and Jura," *Q.J.G.S.*, lxxxix, 1933, 125–144.
9. ANDERSON, J. G. C. "The Dalradian Succession in the Pass of Brander District, Argyll," GEOL. MAG., lxxii, 1935, 74.
10. GREGORY, J. W. *Dalradian Geology*, 1931, 127–9.

EXPLANATION OF PLATE XIII.

FIG. 1.—The increase in andalusite towards the inferred top of an andalusite-schist bed; best seen to the left of the hammer.

FIG. 2.—Boulder showing a succession of three andalusite-schist beds, the inferred youngest being on the left.

The Formation of the Hydraulic Limestones of the Lower Lias.

By P. E. KENT, University College, Nottingham.

AS a result of a study of the Liassic limestones of the Dorset coast, Dr. W. A. Richardson (1923) concluded that both the limestone bands and the nodules were of secondary origin, and largely displaced the associated marls and shales. Observations made during a study of the Hydraulic Limestone Series (pre-*planorbis-johnstoni* subzones) in south Nottinghamshire lend support to the hypothesis of concretionary origin, but do not accord with certain other of Dr. Richardson's suggestions.

The limestones are uniformly fine-grained, and nearly always massive, but frequently show traces of bedding planes and shelly bands. In the lowest layers wedge-bedding of the shelly bands is often visible. When freshly uncovered the limestones appear to pass upwards and downwards into shale, but after weathering the boundary is seen to be sharp. The limestone surface is usually flat, but is occasionally irregular. Above one of these latter beds a *Dapedius*, which lay on its side flattened on a bedding plane, had its venter embedded in shale and its dorsum in limestone. The surface of this bed therefore cut the stratigraphical planes. This and the presence of bedding in the limestones indicates that the limestones are secondary, but shows that they are *replacive*, not

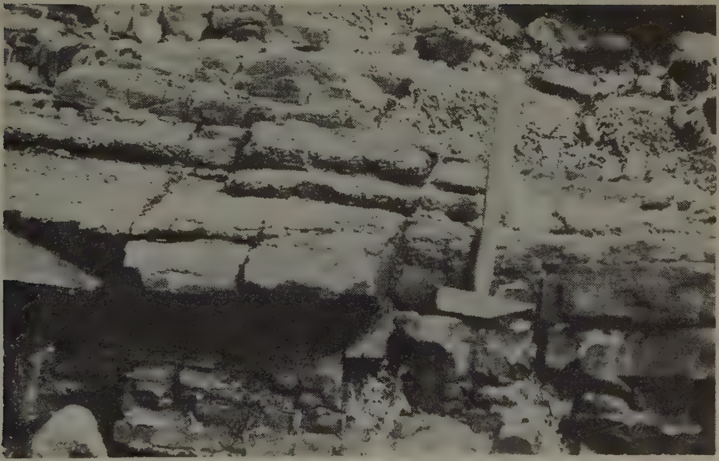


FIG. 1.—THE INCREASE IN ANDALUSITE TOWARDS THE INFERRED TOP OF AN ANDALUSITE-SCHIST BED; BEST SEEN TO THE LEFT OF THE HAMMER.

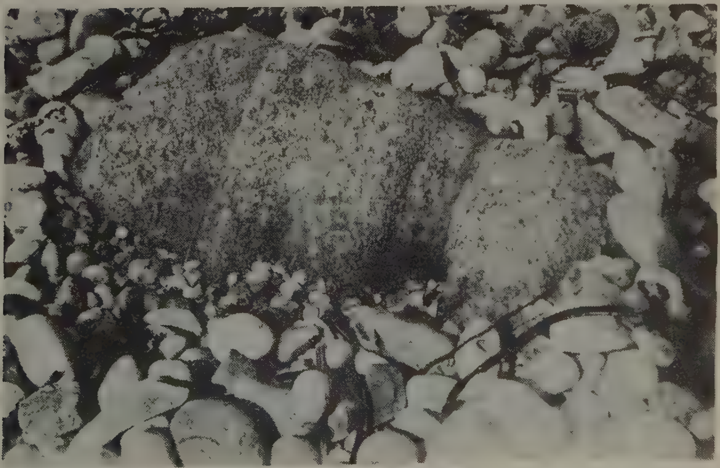


FIG. 2.—BOULDER SHOWING A SUCCESSION OF THREE ANDALUSITE-SCHIST BEDS, THE INFERRED YOUNGEST BEING ON THE LEFT.

displacive, concretions. It is not molecular replacement, but is analogous to the organic process of intussusception.

The limestone bands often thicken locally round a large fossil, usually a saurian skeleton. In one instance a limestone bed 4 inches thick increased to 10 inches, where it enclosed a large *Nautilus*, and developed septarian structure. Adjacent limestone bands are sometimes of complementary thickness. This feature is noticeable in the lowest beds, where two limestones separated vertically by a few inches of shale may maintain the same total thickness, because the thinning of one band is compensated for by thickening of the other.

The pelecypods of the shales between the limestones are nearly always decalcified. This effect cannot be ascribed to the action of seeping water since uplift of the strata, for it is more marked in the lower than the higher shale beds, and at one level in the shale, which was a pronounced line of seepage, the abundant bones and oysters of a fossil bed were almost unaffected.

The fauna of the limestones of the series is practically the same as that of the shales. The few exceptions are very rare fossils, which have only been found at one level; for example, *Heterastraea* has been found in the shale and *Waldheimia* in the limestone, but these do not invalidate the generalization. The occurrence of *Isocrinus* may be taken as an index of clear water conditions, and although it is not common in the Hydraulic Limestone Series it is found at levels where there is independent evidence of slow or interrupted deposition, and occurs in both shale and limestone. The mollusca and vertebrates are found uniformly throughout the limestone and shale. There is thus no faunal evidence whatever to suggest that the limestone beds were deposited as such.

One must, therefore, conclude that the Hydraulic Limestones are of secondary origin.

The time of formation of the limestones can be ascertained within narrow limits. The limestones obviously predate all earth-movement and the formation of jointing. In addition, the fossils included in the limestone are nearly all uncompressed. The bones of saurian heads, which would be dislocated by very slight pressure after the decay of the soft parts, are found to be undisturbed in the limestone. The gas chambers of thin-shelled ammonites, unfilled by sediment, are invariably crushed in the shale, and may be partly crushed in the limestone, but numerous uncrushed examples can be collected in certain limestone bands. Other fossils show similar evidence. It is therefore evident that the limestones were formed before many feet of strata had accumulated above, and this implies that they were formed successively, so that the limestone bands of the "*planorbis*" zone predate those of the "*bucklandi*" zone, and so on.

In south Nottinghamshire the pelecypods in the shale of the lower part of the Hydraulic Limestone Series are more completely decalcified than those in the upper shales, although similar shells in the interbedded limestone bands were unaffected. This suggests that the diffusion of calcium carbonate to the limestone beds was carried further in the lowest strata. It seems possible that the diffusion was checked by the sealing off of the beds by the thick deposit of clay (" portlocki " subzone) which rests on the limestones, so that the segregation of calcium carbonate had proceeded almost completely in the older, lower beds (pre-*planorbis* beds), but less completely in the younger, higher beds (" *planorbis* " and " *johnstoni* " subzones).

Dr. Richardson had concluded (op. cit., p. 97) that the limestone suite is the product of one process of rhythmic deposition, later in date than any contemporaneous erosion that may have affected any portion of the deposits. The preservation of the fossils, and the different degree of decalcification of the shale beds mentioned above, show that this conclusion should not be accepted. In Dorset Dr. Richardson found no reason to believe that any of the concretionary limestones had been eroded, but in the Lias of north Leicestershire, at Old Dalby, bored limestone nodules do, in fact, occur, and a bored slab of the " Ostrea " bed of the Hydraulic Limestones was found on the site of an old quarry between Clipston and Cotgrave (south Notts). The absence of eroded limestone beds in association with the non-sequences in the Lias of Dorset may indicate that the absence of subzones is due to non-deposition instead of erosion, and does not prove that limestone bands had not been formed at the time.

Thus one may conclude that the limestone bands are of secondary origin, that they are concretions of mainly replacive character, and that they were formed very soon after the deposition of the individual beds.

I am indebted to Professor H. H. Swinnerton for reading the manuscript and for making helpful suggestions.

REFERENCE.

Richardson, W. A., 1923. " On the Petrology of the Shales-with-' Beef '," *Quart. Journ. Geol. Soc.*, lxxix, part 1, pp. 88–98.

CORRESPONDENCE.

CHALK AT TRIMINGHAM.

Sir,—A chance meeting on Trimingham beach in July brought me the acquaintance of Mr. J. E. Sainty, and also news from him of a new exposure of Chalk at the foot of the cliff just in the parish of Sidestrand and about a quarter of a mile south-east of the Overstrand Hotel. This exposure when I saw it consisted of a very flat arch (about 100 feet long and 7 feet high above the beach) of sponge bed about 6 inches thick, resting on very soft white Chalk with many large flints. I found the usual fossils of the Beeston to Cromer foreshore Chalk, and none to suggest any higher horizon. The sponge bed was the hardest and most uniform, and the very abundant sponge casts the sharpest I have seen in the *Belemnitella mucronata* Chalk of Norfolk; and the flints were as carious as those of the *Micraster cor-testudinarium* Chalk of Sussex. In the middle of the arch the sponge bed could be seen to slope upwards into the cliff at a low angle for about 10 feet to the foot of a straight face of Crag some 12 feet high, with a strongly marked band of shells running through it. It was not possible to say whether the Chalk was *in situ* or an erratic; but I strongly expect to find it an erratic.

R. M. Brydone.

12c Upper Montagu Street,
London, W. 1.
10th September, 1936.

THE DEFINITION OF AUGITE-BIOTITE-DIORITE.

Sir,—" Unless we shall first establish what is a modius and what is a balance, how shall we be able to measure or weigh anything ? " These words of Epictetus came to my mind when I read Miss Reynolds' reply to Professor Bailey in the August number of Geol. Mag. Professor Bailey appears to have confused a rock that Miss Reynolds calls augite-biotite-diorite with gabbrodiorite. In her reply Miss Reynolds says :—

" The typical augite-biotite-diorite is a highly undersaturated rock. It might equally well be described as biotite-essexite-gabbro. These rocks should not be confused with gabbrodiorite."

To a student of rock names these statements are very disconcerting. A diorite which might equally well be described as an essexite-gabbro! A rock which contains modal quartz and is yet " highly undersaturated "! Miss Reynolds refers us to Tröger's *Kompendium*, p. 146. Following up this reference, I find that the characteristics of the gabbrodiorite family are the presence of a plagioclase near An_{50} in composition; more than 10 per cent of dark minerals; quartz and felspathoids either absent or present in small quantity. The mode chosen to represent the species contains 6 per cent of quartz and orthoclase, 53 per cent of plagioclase (An_{50}), and 41 per cent of pyroxene, biotite, and accessories. Tröger also defines essexite-gabbro as a "plagioclase-rich, feldspathoid-poor essexite with $An > 50$", and gives the following mode: plagioclase (An_{52}) 31 per cent, alkali-feldspar 17 per cent, augite, olivine, and accessories 48 per cent.

Turning now to Miss Reynolds' 1934 paper, p. 611, I find that the augite-biotite-diorite of Slievegarron contains 45 per cent of plagioclase (An_{35}), 49 per cent of augite, hornblende, and biotite, and the usual accessories. "A trace of orthoclase and quartz" is included in the figure for plagioclase. Comparing this mode with those quoted above, I must agree with Professor Bailey that gabbro-diorite is the most appropriate name for the rock. It is not an undersaturated rock in the sense in which I and others have used that term for the last twenty years. The fictitious appearance of olivine and nepheline in the norm has nothing to do with the case, because all current definitions are based on modes, not on norms. The difference between norm and mode in this case results from the unusually high proportion of biotite in the rock. Miss Reynolds claims that the "petrological affinities" are very different from those of gabbrodiorite. This argument leaves me cold. It has been my experience that when a petrologist begins to talk about petrological affinities he is generally begging the question.

I think Miss Reynolds owes it to her readers either to conform to accepted definitions of names and terms, or else to explain clearly what meanings she herself attaches to them.

S. J. SHAND.

STELLENBOSCH,
SOUTH AFRICA.
8th September, 1936.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXIII.

No. XI.—NOVEMBER, 1936.

ORIGINAL ARTICLES.

Fish Remains from the North Wales Coalfield.

By Alan Wood.

Introduction and Review of Previous Research.

At certain levels in the Coal Measures of North Wales a flood of fish scales and bones occurs, to the exclusion of almost every other fossil; at others only an isolated scale or tooth is seen. The area appears to be especially rich in fish remains, though possibly this is due to inadequate collecting in other areas. A summary of the succession in the Flintshire and Denbighshire portions of the coalfield is shown in the diagram on p. 483, while the area dealt with is shown on the map (p. 482).

Hull in 1873[1] recorded the presence of *Rhizodus*, *Coelacanthus*, *Platysomus*, and *Palaeoniscus* in the Coal Measure shales of Denbighshire, this being the first account of fish from the area. The Geological Survey[2] noted the presence of a fish bed above the Badger Coal of the north of Flintshire and the equivalent Premier and Wall and Bench Coals further south, and, in the Flint memoir, *Coelacanthus*, *Elonichthys*, *Rhizodopsis*, and (?) *Strepsodus* were stated to occur above this seam. The fish bed was considered by the Survey to die out to the south before reaching Ruabon, but recently H. H. Simpson[3] proved that this bed extends to the south of Ruabon. He found the fish remains termed *Pleuroplax rankinei* H. & A., *Rhizodopsis sauroides* (Will.), *Megalichthys*, and *Coelacanthus* in it. The same author[4] discovered a fish band in the Ruabon Marl containing *Gyracanthus*, *Megalichthys*, *Ctenodus murchisoni* Ag. MS., Ward, and *Callopristodus pectinatus* Ag., which still remains an isolated record for the Upper Coal Measures of this area. Several new fish bands in the Middle Coal Measures are described in the present paper, and attention is given to the conditions of their formation.

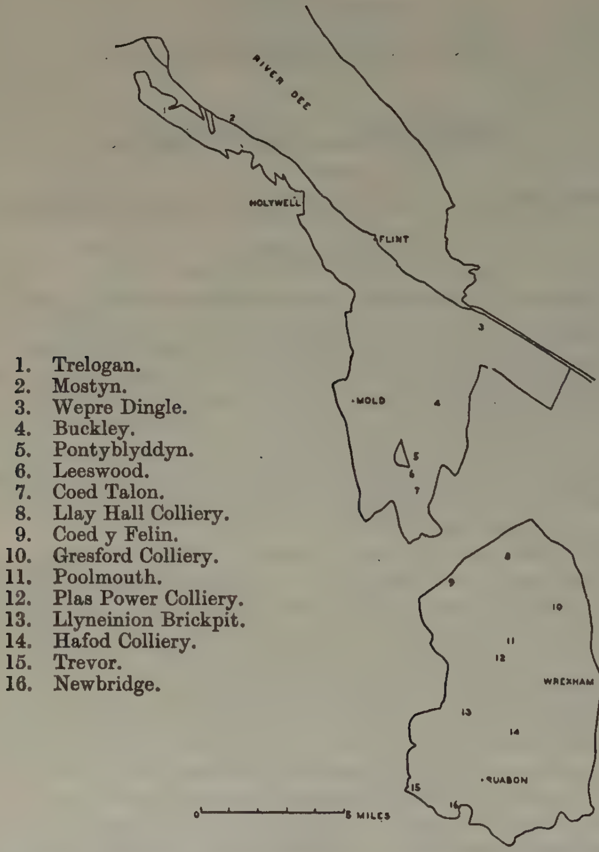
---

[1] E. Hull, *The Coalfields of Great Britain*, 3rd ed. (1873), 8vo, London.

[2] C. B. Wedd and others, *The Geology of Liverpool*, 1923; *The Geology of the Country around Flint*, 1924; *The Geology of the Country around Wrexham*, 1927.

[3] H. H. Simpson, "The Fish Bed in the Denbighshire Coalfield." Geol. Mag., LXX, 1933, 275.

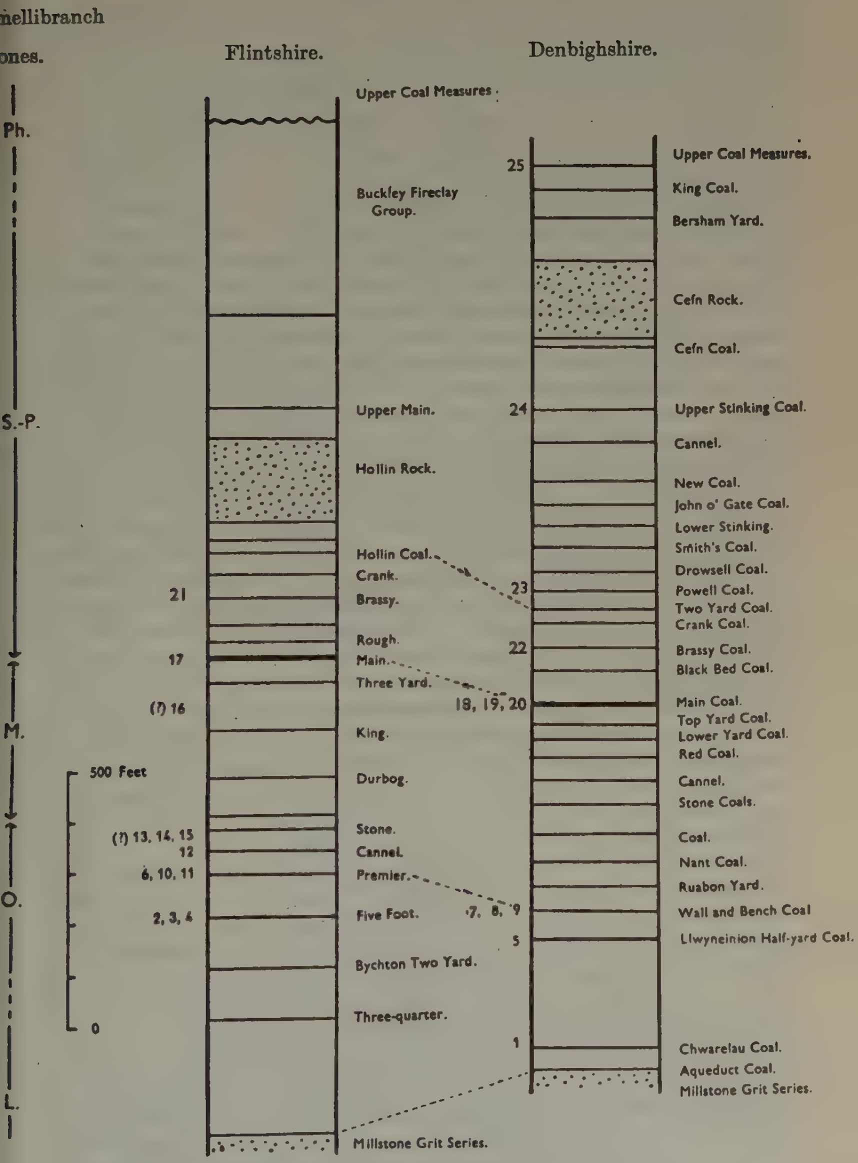
[4] H. H. Simpson, "Note on the Fishes of the Ruabon Marl," Geol. Mag., LXXI, 1934, 280.



Text-fig. 1.—Map of the area dealt with, showing fossil localities.

Occurrence of Fish Remains in the Middle Coal Measures.

Scales of several types may occur on different parts of the same fish, a fact which renders specific determination rather difficult. The literature of the subject is also very scattered, so that usually only generic determinations have here been made. When absolute



TEXT-FIG. 2.—The succession of coal seams in North Wales (after the Geological Survey) with lamellibranch zones (A. Wood).

identity of the forms seemed reasonably certain, specific names have been given, but many of the commonly used specific names appear to have been interpreted rather widely in the past. Pruvost[1] may be consulted for the generic characters as shown by isolated scales.

A diagram facing p. 487 gives in tabular form the distribution of remains in the Middle Coal Measures. Only a few of the localities need be mentioned in detail.

The assemblage above the Half-Yard Seam at Leeswood may be taken as an ideal case, since the remains are abundant and well preserved. At Leeswood Valley Colliery (a temporary adit into the hillside on the left bank below the chapel) the roof is a dull black fissile shale often crowded with fish remains of all sizes. Large jugal plates of *Coelacanthus* lie on the same bedding plane as the small scales of *Elonichthys* or the minute skin-granules of elasmobranchs. There is no evidence that sorting has taken place. Spines of *Acanthodes wardi* Egert. are particularly abundant. The scales of *Coelacanthus* differ from those of *C. elegans* Newb. in that the ridges on the exposed part of the scale do not converge towards the centre line but remain parallel to each other as they run towards the margin. A few of these scales have in addition a delicate radial striation at the border and a prolongation of the free edge into a mucro, which is characteristic of *C. mucronatus* Pruvost. Other specimens, however, are only distinguished from *C. elegans* by their parallel ridges. Palaeoniscids occur abundantly (*Rhadinichthys* Traq., *Elonichthys* Giebel.), but platysomids are only occasionally seen (*Cheirodus striatus* H. & A., *Platysomus* Ag.). The majority of the scales of *Rhadinichthys* are smooth except for a few striae parallel to the anterior and inferior margins. Judging from their proportions some of these scales should come from the middle of the fish, and it is possible that this is an undescribed smooth-scaled species, rather than an aggregation of scales from the posterior region of an ornamented form.

The most varied fauna from higher levels is found above the Brassy Seam at Elm Colliery, Buckley. Conditions of preservation are very like those seen above the Half-Yard Seam, but there are certain differences in the fauna. *Pleuroplax attheyi* Barkas in which the ridges of the individual fused teeth are continuous right over the crown, is not present at lower levels. The specimens of *Rhizodopsis* appear to be different from those found near the Wall and Bench Seam, being broader and stouter, while no *Rhadinichthys* scales with tuberculate ornament have been seen at this higher level. Scales of the true *Coelacanthus mucronatus* type have not been secured, though scales with parallel ridges which differentiate them from the associated *C. elegans* are abundant.

---

[1] P. Pruvost, "La Faune continentale du Terrain Houiller de la Belgique," *Mem. Mus. Roy. Hist. Nat. Belg.*, 44, 1930, 105.

CONDITIONS OF FORMATION OF FISH BANDS.

Many of the fish bands present interesting problems in the state of preservation of the fossils or the nature of the surrounding rock. The bed above the Half-Yard Seam, as mentioned above, contains well-preserved scales and bones which show no signs of sorting by water. Bands at other horizons, however, betray the influence of this process. At Llwyneinion brickpit to the west of Wrexham the fish bed above the Wall and Bench Coal can be seen in situ. The actual fish-bearing layer, lying just above the coal, is thin, and the fish remains are unusually small. Even coprolites are represented only by broken portions. The shagreen platelets of elasmobranchs are extraordinarily abundant, and are accompanied by many indeterminate fragments of bones and scales, small teeth, and a few whole scales of *Rhadinichthys.* Notwithstanding the abundance of the outer covering of elasmobranchs their teeth and spines are represented only by solitary specimens—namely, a tooth apparently falling into the genus *Pleuroplax* A. S. Woodw. and a broken spine of *Acanthodes.* Such an unbalanced collection of small fossils is certainly not due to unfavourable conditions of life but to current-winnowing. Save for the spine and the tooth, the deposit is quite well graded, and it is easy to picture a weak current driving these minute fossils before it into some sheltered spot.

A fish band occurs in a parting within a coal seam at Poolmouth, Moss Valley, north of Wrexham. The Upper Stinking Coal is here divided, and only the lower portion, separated from the upper by the parting, is worked. Immediately above this lower coal is a hard black shale, almost a cannel coal, which encloses the fish remains. The band is about one inch thick. Above the fish bed the rock becomes duller and less splintery, and after a couple of inches rootlets appear and ramify abundantly over the surface of the shale. The fish remains in the fossiliferous band are comminuted. Many fragments of bones occur and a few fragments of coprolites. Identifiable remains are rare, perhaps the most abundant genus being *Platysomus*, represented by broken scales. Other localities yield *Platysomus* only sparingly, so that this abundance is unexpected. *Rhizodopsis*, too, is more frequent than is usual. *Elonichthys* and *Rhadinichthys* are rarer, while *Coelacanthus* is very scarce, being represented only by a few scales belonging to *C. elegans* Newb. It might be thought that the scarcity of the latter is due to the fragility of its scales as compared with, say, *Rhizodopsis*, but this would not account for the absence of jugal plates. Shagreen of elasmobranchs is found, but is by no means characteristic. The fish assemblage in this deposit appears to have been originally somewhat unbalanced, a feature which may have been accentuated by comminution of the remains. The processes which led to this comminution are not easy to formulate. Submersion of the coal seam could not have been very great, for the seam continues on after the parting, so that the action of waves in breaking up the fish scales and bones must be ruled out. Probably the best explanation is that they were broken up by organic agencies after the death of the fish—either by other fish or by them in combination with such soft-bodied creatures as worms which devour and grind the muddy floor and its contained organic matter.

It is specially noticeable that abundant fish remains are chiefly found in dull black fissile shales. Occasionally, by an increase in the decomposed vegetable content (and perhaps in its fineness of division). these rocks lose their fissility and pass over into bastard

	1.	2.	3	4	5.	6.	7.	8.	9.	10.	11.	12	13	14	15.	16.	17.	18.	19.	20	21.	22.	23	24	25.
Coelacanthus elegans Newb.			×			×				×				×		×					×			×	
C. mucronatus Pruvost		×																							
C. cf. *mucronatus* Pruvost		×	×	×		×				×	×			×	×						×				
C. sp.	×						×	×			×	×									×		×		
Platysomus sp.		×	×			×				×											×			×	
cf. *Platysomus*					×																				
Cheirodus striatus H. and A.		×																							
Cheirodus sp.				×																					
cf. *Cheirodus*						×																			
Drydenius molyneuxi Traq.			×	×		×																			
Elonichthys spp.		×	×	×		×		×		×	×			×	×						×			×	×
Rhadinichthys spp.	×	×	×	×	×	×		×	×	×	×			×			×				×		×	×	
Megalichthys hibberti Ag.		×															×								
M. cf. *coccolepis* Young																	×								
M. sp.												×	×									×			
Strepsodus sp.		×				×		×																	×
Rhizodopsis sp.		×	×		×	×		×						×		×					×			×	
Acanthodes wardi Egert.		×	×			×		×		×	×	×									×				
A. sp.									×																×
Elasmobranch shagreen		×	×		×	×		×	×	×	×													×	×
Pleuroplax rankinei H. and A.								×				×													
P. attheyi Barkas																					×				
P. sp.		×							×																
Diplodus sp.		×																							
Anterior tooth of cochliodont			×																						
Palaeoxyris sp.																		×	×						
Vetacapsula kidstoni Crookall																				×					

TEXT-FIG. 2. The distribution of fish remains in the Lower and Middle Coal Measures of North Wales.

cannels. Fish remains then appear to become more sparsely distributed. This restriction of abundant fish remains to one rock type is probably not accidental, and three possible explanations may be advanced.

(1) The fish remains and the fine mud particles in which they are contained had the same mass when submerged; hence when a current swept along the bottom they were transported together and deposited in the same place.

(2) The fish had a predilection for the places in which this type of deposit occurred.

(3) The fish were spread everywhere, but this type of deposit was accumulated with extreme slowness so that the fish remains formed a considerable portion of the sediment.

Hypothesis (1) can be ruled out as a general explanation, for occasionally portions of fish occur in which the individual bones and scales are in the position of life. In such a case there can have been little transport. Sometimes traces of current action can be distinguished, as has been noticed above, but in other cases large head bones and small scales, the large scales of *Rhizodopsis* and the minute shagreen of selachians all occur pell-mell on one bedding plane.

It seems possible that a combination of hypotheses (2) and (3) gives the best picture of what actually happened. It appears to be agreed that the formation of cannel took place by decomposition of vegetable matter under water, culminating in the formation of a sapropel. This process, naturally, took some time to complete. The still bays, inlets, and pools in which such a slow decomposition was proceeding would contain a rich food supply for the smaller forms of Carboniferous fish. Should the supply of decomposing plant débris be too great, acids would accumulate, and there would be a tendency for the fish population to fall off. Therefore the most numerous fish population would occur in areas where the incoming plant matter was sufficiently small in amount not to poison the water, and hence we find the most numerous fish fossils not in the purer cannels but in varieties contaminated with mineral matter.

The writer wishes to acknowledge his indebtedness to Drs. E. Neaverson and W. F. Whittard, who have read through the manuscript and suggested improvements of presentation.

LIST OF FOSSIL LOCALITIES (*see* FIG. 3).

1. Twelve feet above Chwarelau Coal, Australia Brickpit, Trevor.
2. Half-Yard Coal, Leeswood Valley Colliery, 60 yards south-south-east of Vale View Terrace, Leeswood.
3. Half-Yard Coal, Pontybodkin, near Leeswood.
4. (?) Do. Dingle Wood, Pontyblyddyn.
5. Llwyneinion Half Yard, Frwd Wood, Coed y Felin.
6. "Yard" (= Wall and Bench) south of Celyn Farm, near Leeswood.
7. Wall and Bench Coal, Hafod Colliery.
8. Do. Llay Hall Colliery.

9. Wall and Bench Coal, Llyneinion Brickpit.
10. Do. Wepre Dingle, Shotton.
11. Wepre Dingle, south of Hall.
12. Cannel Coal, Clydewog Valley, south of Tan Llan Colliery, Coed Talon.
13. Nant y Ffynnon Lwyd, Mostyn, by seam west of "Anticline".
14. Nant y Ffynnon Lwyd, Mostyn, second *Carbonicola* band 250 feet vertically below final coal seam.
15. Nant y Ffynnon Lwyd, Mostyn, third *Carbonicola* band, 38 feet above last.
16. Head of Byr Brook, Coed Talon.
17. Main Coal, Alyn Bank Colliery, Pontyblyddyn, near Mold.
18. Main Coal, Bersham Colliery, near Wrexham.
19. Do. Big Mancot, near Hawarden.
20. Do. "Old Shaft," 750 feet south-west of Old Talwern Colliery, Coedpoeth.
21. Brassy Seam, Elm Colliery, Buckley.
22. Do. Gresford Colliery.
23. Powell Coal, Plas Power Colliery.
24. Upper Stinking Coal, Poolmouth, Moss Valley.
25. New Bridge, River Dee, south of Ruabon (top of Middle Coal Measures).

On the Structure and Affinities of the Carboniferous Cochliodont *Helodus simplex*

By J. A. Moy-Thomas, Lecturer of Christ Church, Oxford.

(PLATES XIV AND XV.)

Introduction.

Of all the groups of fossil fishes the anatomy of the Cochliodonts is perhaps the least known. Only in *Menaspis* (Jaekel, 1891; Dean, 1904; Weigelt, 1931), *Oracanthus* (Traquair, 1888; Smith Woodward, 1915; Moy-Thomas, in the press), and *Helodus* (Smith Woodward, 1898, 1921, 1932) is anything known, beyond the teeth and occasionally associated spines. Nevertheless it has long been suspected (Owen, 1840; Egerton, 1872; Jaekel, 1891; Smith Woodward, 1932) that the Cochliodonts were to some extent related to the Chimaeroids. The following work was undertaken in the hope of further elucidating their affinities. *Helodus* is a particularly suitable fish on which to work because it is generally supposed to be the least specialized of all Cochliodonts, as none of the teeth is fused into large teeth plates, and the number of successional series is greater than in any other member of the group and consequently its anatomy is almost certainly typical of all Cochliodonts.

The history of the genus *Helodus* is rather complicated, but Smith Woodward (1889), in vol. i of his "*Catalogue of Fossil Fishes*, sums up the position of the genus in the following way:—

"As originally defined by Agassiz, the generic name *Helodus* is applicable to all detached anterior teeth of Cochliodonts; but in the absence of definite evidence, it seems advisable to restrict the term provisionally to the type species, which represents a genus still awaiting elucidation. This fish is obviously very closely related to

Pleuroplax, as is shown both by the dentition and the dorsal fin spine (Ward, 1875); but in the known examples of the last-named genus all the teeth are described as fused into plates, while in the typical *Helodus* no such arrangement has been discovered" (Traquair, 1888). Davis (1890) described specimens of the type species of *Helodus*, *H. simplex*, in which some of the teeth were fused into Pleuroplax plates and concluded "not only that the two genera had similar spines but that they are one species with the same spine".

This view was not entirely accepted by Smith Woodward. I quote the following from some unpublished notes in the British Museum (Natural History): "It still remains uncertain whether *Pleuroplax* is generally distinct from *Helodus*. Although dental plates of the form named *Pleuroplax rankinei* are now definitely known to occur in the jaw of *Helodus simplex*, it is clear that they do not replace more than one or two of the eight or nine transverse series in each ramus; whereas in the type jaw of *P. rankinei* (Hancock and Atthey, 1872) . . ., the transverse series of teeth are fewer than in *H. simplex* and all are fused into plates. It must also be noticed that dental plates of *Pleuroplax* are sometimes abundant in strata in which the teeth of *Helodus* are rare or unknown." (Davis, 1879, and Bolton, 1905.)

All the material described in this paper has teeth of both *Helodus simplex* and *Pleuroplax rankinei* occurring in the jaws and I have therefore not had to attack the problem as to whether *Helodus* is generically distinct from *Pleuroplax*, as on the above definition of Smith Woodward it all falls under the name of *Helodus simplex*. In the course of this work it has also been possible to point out that the genus *Diclitodus* (Davis, 1883) is a synonym of *Helodus simplex*, as these teeth are shown to occur at the symphysis of the jaws. This has already been pointed out in Smith Woodward's unpublished notes.

Previous knowledge of the anatomy of *Helodus* is entirely due to Smith Woodward (1898, 1921, and 1932). In 1898 he states "The genus *Helodus* . . . has at least one dorsal fin, while the pectorals are neither much enlarged nor 'archipterygial'. An anal fin is also present". In 1921 he states "the generalized *Helodus* is represented in the British Museum by several portions of skeletons. In these fossils there is no trace of the vertebral axis which must have been notochordal. The paired fins seem to resemble those of a modern Selachian, and the anterior dorsal fin is provided with a spine. The posterior dorsal fin seems to have been without a spine, as in the Chimaeroids." In 1932 he added nothing further to this description.

The material of *Helodus* examined during the present work was mostly collected by John Ward and all belongs to the British Museum (Natural History) and comes from the Knowles Ironstone, Fenton, Staffordshire, except the specimen described by Davis, 1890, which is V. 2935 of the Hunterian Museum in the University of Glasgow. All the numbers of specimens mentioned below refer to specimens in the British Museum. I am very grateful to Dr. E. I. White of the British Museum and to Dr. E. D. Currie of the Hunterian Museum for access to the specimens in their respective charges. I am, however, most deeply indebted to Sir Arthur Smith Woodward for the loan of his unpublished notes, and for his encouragement during this work. Before proceeding further I would like to take this opportunity of thanking Professor Goodrich for reading and criticizing this manuscript. The photographs were all taken by Mr. P. A. Trotman, for whose services I am very grateful.

All the material was prepared with a light hammer and fine chisels. As the ironstone was very hard and the specimens rather fragile, the material was not always developed as much as would have been liked, but a series of lucky fractures in the skull of P. 8212 made it possible to give a fairly full account of the cranial anatomy.

THE GENERAL BODY CHARACTERS.

Helodus simplex Ag. appears to have been a fish about 45 cm. (Text-figs. 1 and 2) in length, the head occupying about a seventh of the total body length. The head and body are not covered by any large spines. There is only a shagreen of small dermal denticles. The body seems to have been broader anteriorly than posteriorly and there is a general tendency towards tapering at the posterior end.

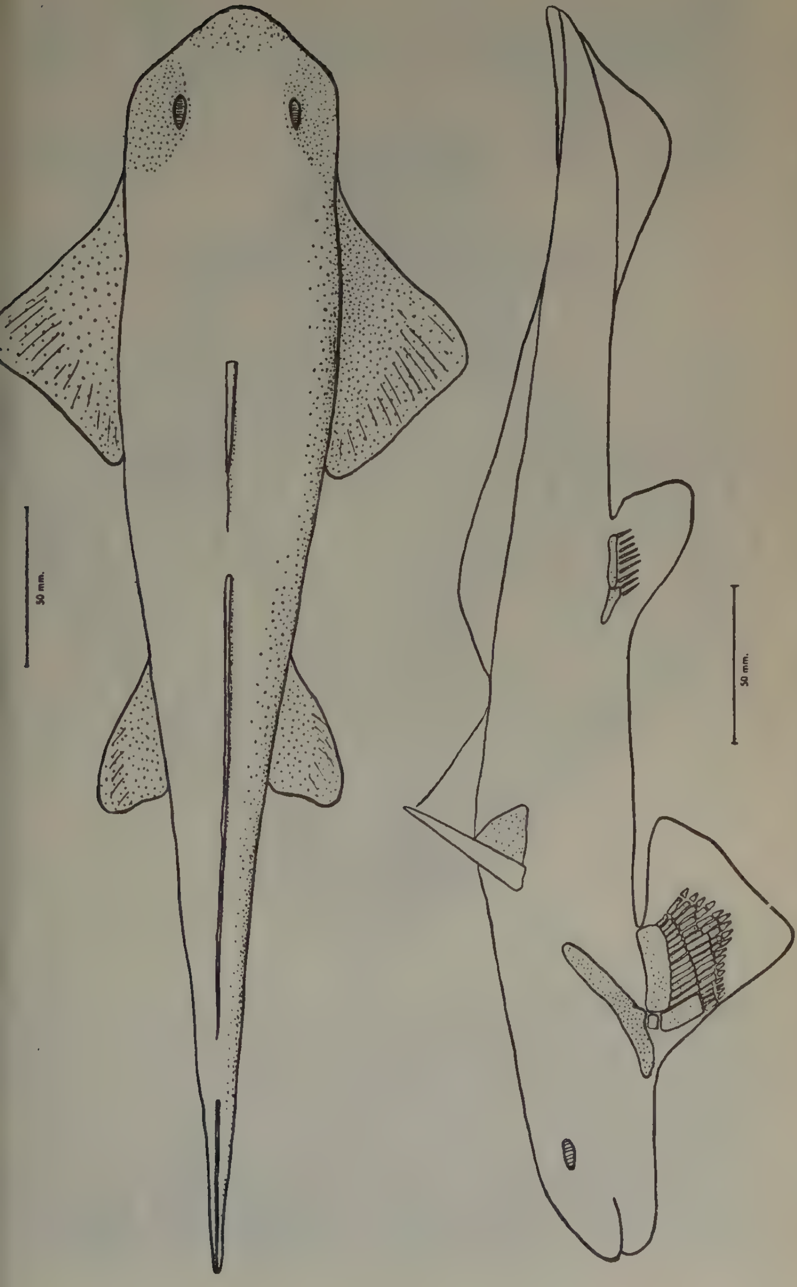
The pectoral fins are relatively large and situated close behind the head, slightly in front of the dorsal fin spine. The pelvic fins are situated about half-way down the body and are considerably smaller than the pectorals. There were apparently two dorsal fins, but their limits are not clearly defined in any of the material examined. The anterior dorsal fin, however, had a smooth laterally compressed fin-spine. The caudal fin was heterocercal.

The skeletal elements are entirely cartilaginous, except the dorsal fin spine, and are hollow and filled with calcite. This shows that their calcification must have been in life restricted to the minute tesserae on the outer surfaces, which are nearly always well preserved.

The Dentition.

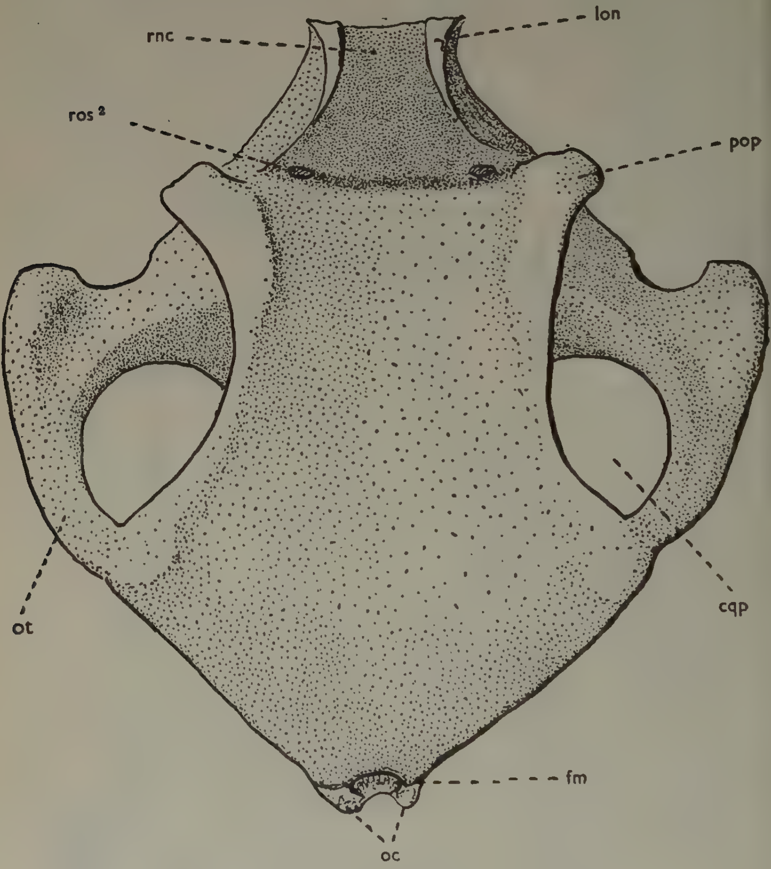
Three kinds of teeth occur in the jaws of *Helodus simplex*. Those which are known as *Helodus simplex*, those which are known as *Pleuroplax rankinei*, and the tooth termed *Diclitodus* (Davis, 1883). Although teeth are present in every specimen examined it is still extremely difficult to give an accurate account of the dentition. There is even great difficulty in establishing the number of teeth on the jaws.

There is, however, one fact which can be established. The teeth at the posterior end of the jaws are small, becoming larger more



Text-figs. 1 and 2.—*Helodus simplex* Ag. Restoration of fish in dorsal view (Fig. 1, above), and lateral view (Fig. 2, below).

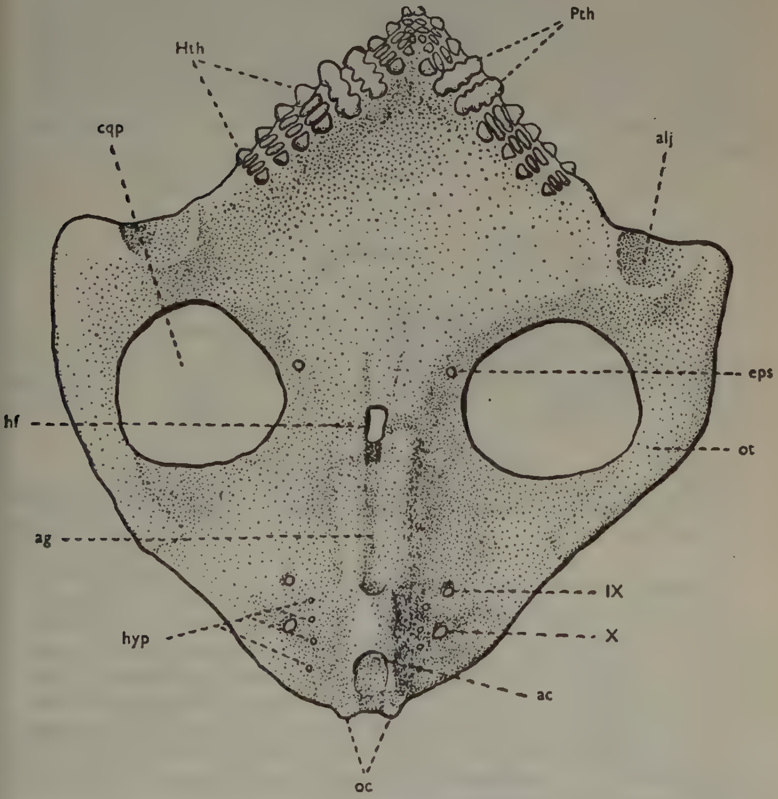
anteriorly and then becoming smaller again at the anterior end. There is therefore a maximum tooth size in the middle of the jaws as in *Cestracion.* The teeth occur in apparently slowly replacing successional series with about five teeth in each series. Nearly every specimen examined had some of these series fused into *Pleuroplax* plates, intead of successional *Helodus* teeth, and in the symphysial region of the lower jaw teeth of lateral rows are fused into the " *Diclitodus* " type.



Text-fig. 3.—*Helodus simplex* Ag. Restoration of dorsal view of the skull. The extreme anterior end is slightly truncated. For lettering of this and subsequent text-figures, see p. 501. × 1½.

I have never observed more than nine series of teeth, and of these the fifth is the largest and appears generally to be fused into a *Pleuroplax* plate. The number of series fused into *Pleuroplax* plates appears to vary and it is often impossible to be sure whether a tooth is of the *Pleuroplax* or *Helodus* type when only seen in section.

It may be concluded that there are about eight or nine series of teeth in each ramus of the jaw. At the anterior end of the upper jaw teeth from each side lie very close to one another, and in the lower jaw the two rami meet in a symphysis where a small anterior tooth may fuse with its neighbour to give rise to the tooth known as *Diclitodus*.

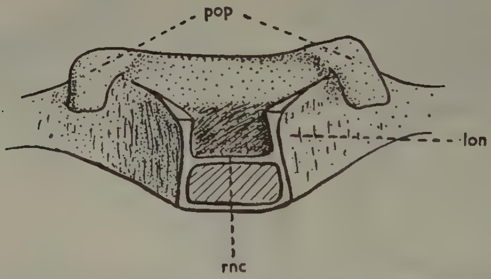


Text-fig. 4.—*Helodus simplex* Ag. Restoration of palatal view of the skull. × 1⅓.

The Skull.

The skull (Text-figs. 3, 4, 5, 6, 7, and Plates) is fairly well preserved in specimens P. 8213*g*, P. 8213*e*, P. 8214, P. 6706, but it is particularly well preserved in P. 8212, and it is from this specimen that most of the following description is taken.

The skull in all the material examined is crushed dorsoventrally, and it is not very easy to be sure of its depth, but it seems very probable that the skull was rather dorso-ventrally flattened in life, and never had a very great elevation. The skull is as broad as it is long, but this is mainly due to the palatoquadrates which are fused completely to the neurocranium, and project laterally to it. This condition in which the palatoquadrates are fused to the neurocranium, as will be shown later, is known as "Holostyly" (Gregory, 1904, see also De Beer and Moy-Thomas, 1935). The skull is broadest at about half its length and tapers anteriorly and posteriorly to a point. The roof (Text-fig. 3) of the brain-case is lower in front than in the middle region, but becomes lower again posteriorly. This is not visible at the anterior end in side view, owing to the upgrowth of the lamina orbito-nasalis. The skull is cartilaginous and has no dermal spines as in some other Cochliodonts.



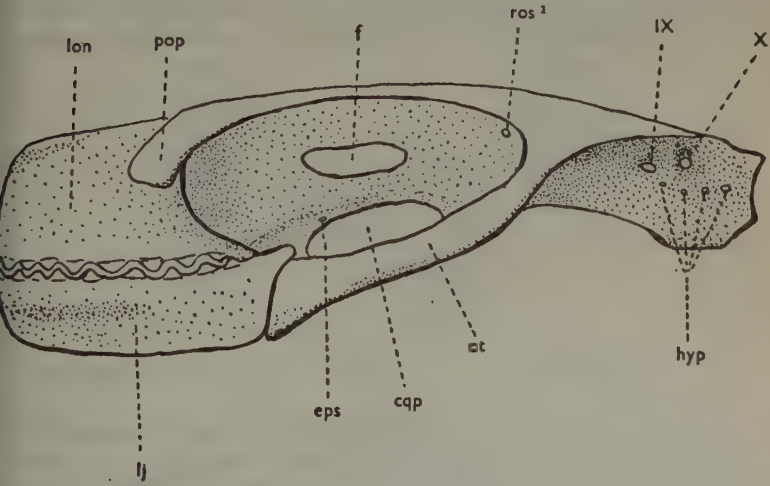
Text-fig. 5.—*Helodus simplex* Ag. Restoration of anterior part of the skull. The teeth are omitted and the extreme anterior end is seen in section. Slightly enlarged.

In ventral view the palate (Text-fig. 4) can be seen to be broad; and posterolaterally to the last tooth, at a point rather more anterior than half the length of the skull, two articular surfaces for the lower jaws are situated. Posteriorly to these surfaces processes are continued backwards to meet the auditory region with which they fuse. There can be little doubt that these processes are the otic processes of the palatoquadrates and strictly comparable to those found in the Holocephali. The space enclosed by these processes is therefore the cranioquadrate passage.

The skull is very extensively roofed and there is a well marked preorbital process. The width of the roof of the skull is equal to about half the length in the middle region but tapers anteriorly and posteriorly.

The ethmoid region (Text-fig. 5) is rather poorly preserved. It is bounded laterally by two wing-like upgrowths which I interpret as the laminae orbito-nasales. The laminae rise up laterally to the roof of this region which is at a lower level than the roof of the posterior part of the skull. At the base of this decline on either side are the remains of foramina, which from their position cannot have been connected with the brain-case, but with the orbit and probably served for the rami ophthalmici superficiales. There is a sharp decline in the level of the roof just in front of the preorbital process, but the tops of the laminae orbito-nasales are at the same level as the posterior part of the roof. Beneath the roof of the ethmoid region are the remains of cartilage, and it is presumed that this region was occupied by the nasal capsules.

The orbitotemporal region of the neurocranium is also rather crushed but it does seem clear that there was a considerable tract which was not cartilaginous, and which I interpret as the fissure in the interorbital septum of the Holocephali. It is, however, not possible to be sure whether this space really lay above the brain. At the posterior end of the lateral part of this region is a nerve foramen which seems most likely to be the foramen for the ramus ophthalmicus superficialis. Ventrally and medially is a large hypophysial foramen, and at the edge of the floor of this region slightly behind the front end of the cranioquadrate passage passing directly up into the orbit is a foramen for the efferent pseudobranchial artery. Unfortunately the cartilage is rather damaged laterally to the hypophysial foramen, and it is possible that other foramina were present in this region. The details of the auditory capsules are not clearly seen, but there is a considerable quantity of calcite in the space occupied by the semi-circular canals. In the occipital region there



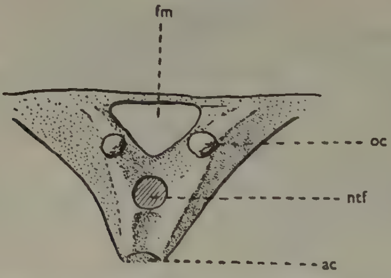
Text-fig. 6.—*Helodus simplex* Ag. Restoration of lateral view of the skull. × 1½.

is a ventral short aortic canal which is continued forward as a shallow groove almost to the hypophysial foramen. Directly posterior to the hypophysial foramen is a deeper depression in the floor of the brain-case. Laterally and dorsally to this canal lie four foramina for the hypoglossal nerves, and dorsally to them two larger foramina for the vagus and more anteriorly for the glossopharyngeal nerves.

In posterior view (Text-fig. 7) the occipital region has ventrally the aortic canal; as this does not begin at the extreme posterior end it is not entirely visible from behind. Dorsally to this lies a foramen undoubtedly occupied in life by the notochord and dorsally to this the foramen magnum. Ventro-laterally to the foramen magnum are two well-marked occipital condyles.

The very broken condition of the roof of the skull in the otico-occipital region makes it impossible to discern whether there were one or two openings for the ductus endolymphatici.

The palatoquadrates, as already noted, are entirely fused to the anterior part of the neurocranium, and are connected posteriorly by the otic process to the auditory region. There is no trace whatever of any suspensory hyomandibular. The branchial arches can be seen in P. 8212 lying as in typical Holocephali beneath the brain-case, but their exact number was not visible, and it was considered unwise to attempt further preparation of this specimen. There can be no doubt, however, that the skull was holostylic. The lower jaws are stout cartilages, more or less triangular in cross section, meeting one another anteriorly in a symphysis. Each ramus ends posteriorly with an articular surface for attachment to the palatoquadrate, and dorsally to this is a short backwardly directed process.



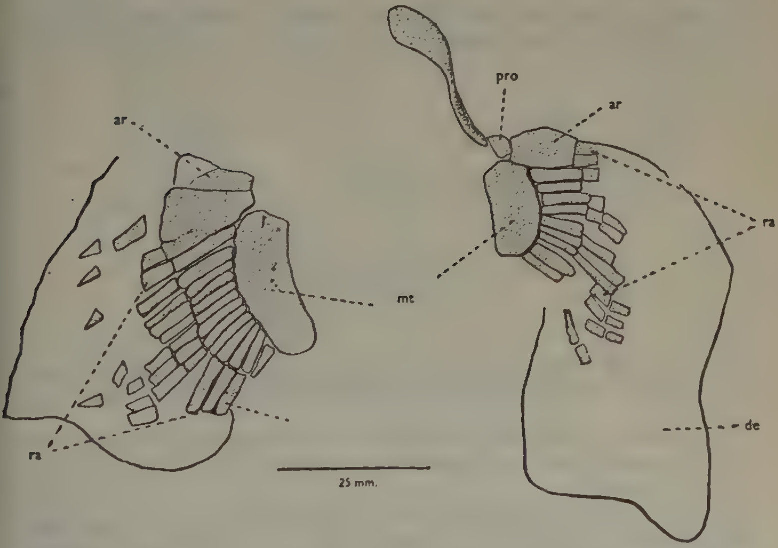
Text-fig. 7.—*Helodus simplex* Ag. Posterior view of the neurocranium. × 1½.

The Axial Skeleton and Unpaired Fins (Text-figs. 1 and 2).

No trace of the axial skeleton is ever preserved and there is, therefore, every reason to believe that the notochord was persistent.

The dorsal fins are not very well preserved. There is a single dorsal fin spine anteriorly with a small posterior triangular cartilage at its base. The dorsal fin spine is smooth and laterally flattened, and has a posterior groove for about three-quarters of its length. The spine is relatively small, being only about a twelfth of the total body length. There are traces of another dorsal fin more posteriorly down the body in P. 8209.

I have not observed any definite anal fin. The complete caudal fin is not preserved in any of the material but a very large part of it is present in P. 8209. Here there is a small but well-marked hypocaudal lobe, and traces of an epicaudal lobe. There is no doubt that the tail was heterocercal. There are no signs of any fin rays in the median fins, which are all covered by a shagreen of small denticles.



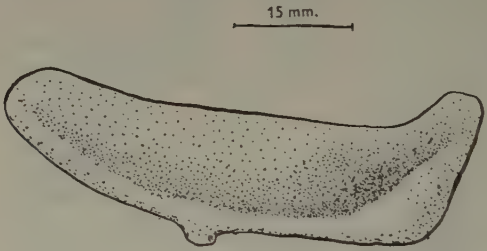
TEXT-FIG. 8.—*Helodus simplex* Ag. Pectoral fins of specimen P. 8212, Brit. Mus. (Nat. Hist.).

The Paired Fins and Girdles.

The pectoral fins and girdles are only really well shown in P. 8212 (Text-fig. 8), although portions of the dermal expansion beyond the ends of the radials are common. This specimen is crushed dorso-ventrally and the fins of both the right and left side are visible in ventral view.

The fins are relatively large and roughly triangular in outline. Two cartilages can be seen articulating with the girdle. The more anterior is a relatively very small, more or less square cartilage seen only on the left side, and is the propterygium. Posterior to this cartilage lies an elongated cartilage about three times as long as it is broad, the metapterygium. Four jointed radials articulate with the distal end of the propterygium, their proximal segments being fused into an enlarged cartilage. This proximal fused part of the radials is nearly twice as long as the next more distal segment, which in its turn is nearly twice as long as the pointed terminal division of the radials. The exact number of radials articulating with the metapterygium is not possible to determine, but there were certainly more than thirteen. Of these the first six are jointed three times and the remainder four times. All the joints are the same size except the most terminal which are pointed and shorter where visible.

There is a considerable shagreen covered dermal expansion to the fin which is at its maximum development about equal in width to the part supported by cartilage. These expansions have very slight impressions of radial striae, which are presumably due to the ceratotrichia.

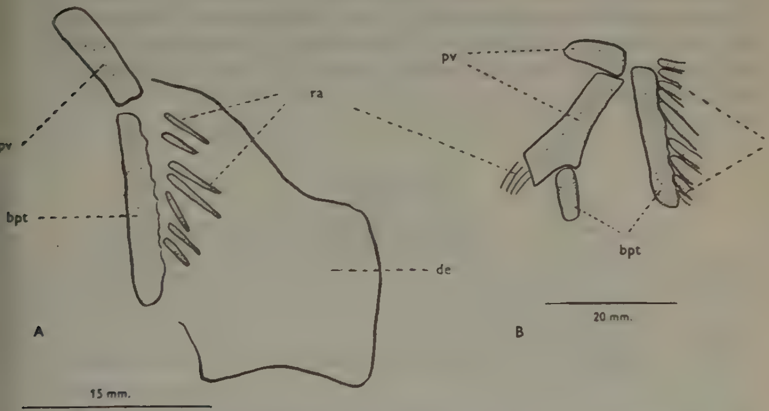


Text-fig. 9.—*Helodus simplex* Ag. Ventral view of the pectoral girdle, somewhat restored, from specimen P. 8212, Brit. Mus. (Nat. Hist.).

The two halves of the pectoral girdle (Text-fig. 9) are separate although closely approximated anteriorly. The girdles are elongated flattened structures, slightly curved in both the horizontal and the vertical planes and their anterior ends produced medially into small processes opposing one another but apparently not articulating. The outer posterior edge is produced backwards forming a posterior ridge running the whole length of the girdle. This ridge is higher ventrally than dorsally and at a point about half the length of the girdle is produced laterally into a small process for articulation with the internal skeleton of the fin.

The pelvic fins and girdle are preserved in P. 8212 and P. 8209, (Text-fig. 10). These fins are considerably smaller than the pectoral fins, but like them have a dermal expansion beyond the cartilaginous radials, which forms about two-thirds of the fin. There is a single elongated basipterygium from which eight or nine relatively short, unjointed, and pointed radials arise.

The pelvic girdle in P. 8212 is represented by two cartilages. The left hand of these is the larger and is lying in contact with the right, and has two radials articulating with it. The right hand cartilage is only about a third the length of the left, and no radials are preserved in connection with it. There seem to be two possibilities. Either these cartilages represent the broken halves of a once continuous bar, or there were originally two separate halves to the girdle. P. 8209, however, supports the latter view as a single right cartilage is preserved unassociated with the left-hand fin and not lying transversely across the body.



Text-fig. 10.—*Helodus simplex* Ag. Pelvic fins of specimens P. 8209*a* and P. 8212*b*, Brit. Mus. (Nat. Hist.).

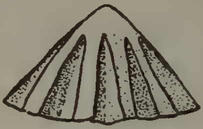
The Dermal Skeleton.

The body, but apparently not the dorsal side of the head, is covered by a shagreen of closely set small denticles. These denticles (Text-fig. 11) are conical in shape and have about ten or eleven grooves running towards the apex of the cone. This ornament of the denticles is seldom clearly shown, but P. 8214*d* has the denticles very well preserved on the expansion of the pectoral fin as casts in which the ornament is clearly visible. The denticles are never sufficiently well preserved for their detailed structure to be determined, but from their shape they might easily have been the typical hollow cones of the Holocephali.

Discussion.

There can be little doubt from the above account of the anatomy of *Helodus simplex* that it is related to the Holocephali. In addition to the remarkable resemblance of the teeth of related Cochliodonts to those of the Chimaeroids, *Helodus* itself has a holostylic skull, the general shape and anatomy of which is built on the same fundamental plan as the Chimaeroids. The pectoral fins with the large metapterygium, small propterygium, and the fused anterior radials, and the pelvic fins with the two halves of the girdles separate and the single basipterygium are all characteristic of the Chimaeroids. Similarly the presence of a spine for the anterior dorsal fin only is very characteristic.

On the other hand *Helodus* differs in many ways and is more unspecialized than the Holocephali in other characters. The cranial roof is broader, and cranioquadrate passage much larger. There is an aortic canal, and a large hypophysial foramen. The teeth of *Helodus* are far less specialized than those of the Holocephali. The two halves of the pectoral girdle are separate, the notochord has no calcareous rings and there are no traces of cephalic or anterior pelvic claspers.



Text-fig. 11.—*Helodus simplex* Ag. Denticle, × 40.

From the above it can be inferred that the Holocephali are close relatives of *Helodus*, and that the latter has no characters which prevent it from being related to the ancestor of the Holocephali, and, as I have suggested (Moy-Thomas, in the press), I believe that they arose directly from the Cochliodonts.

De Beer and Moy-Thomas (1935) suggested that the Holocephali are the most primitive of all living Gnathostomes, having the palatoquadrate fused to the neurocranium and the hyomandibular never having been suspensory. It might also be supposed, however, that the palatoquadrate has become fused with the neurocranium directly in relation to the development of crushing teeth, and that the hyomandibular has secondarily become unsuspensory. *Helodus* provides some important evidence in favour of the former view, because although the teeth of *Helodus* are very unspecialized and hardly at all fused into plates nevertheless the holostyly is as well developed as in the latest Chimaeroid. It therefore does seem possible that the Cochliodonts, Holocephali Chondrenchelyds (Moy-Thomas, 1935), and all the other Bradyodonts (Nielsen, 1932) have diverged from the ancestral stock of Chondrichthyes at a time before the hyomandibular had become suspensory. The chief difficulty presented by this view is that unless claspers were present in the *Cladoselachii*, the most primitive forms of Chondrichthyes with a suspensory hyomandibular, they must have been independently developed in the two groups. It may also be argued in support of this latter view that the skull of *Helodus* is a typically crushing one, and that the Holostyly is directly due to this, the hyomandibular having lost its suspensory function.

The condition of the ethmoid region in *Helodus* is of particular interest in connection with the formation of the ethmoid canal. De Beer and Moy-Thomas (1935) suggested that the ethmoidal canal is an extracranial space, secondarily roofed over in connection with the formation of the interorbital septum. In *Helodus* the roof of the orbital region has become raised relatively to the roof of the nasal capsules and the epiphysial foramen appears to have become roofed over. The foramina present medianly to the lamina orbito-nasalis were presumably for the ramus ophthalmicus superficalis. The laminae orbito-nasales have grown up on either side of these nerves and the rami opthalmici profundi and have not yet been roofed over. This evidence is more in accord with the view of De Beer and Moy-Thomas than those of Allis (1917, 1926, 1934).

SUMMARY.

1. The anatomy of *Helodus simplex* Ag. is described.

2. The skull is found to be holostylic, and to have many characters in common with the skull of the Holocephali, but in some respects is less specialized.

3. The pectoral fins, with their long metapterygium, small propterygium, and fused anterior radials, resemble very closely those of the Holocephali.

4. The pelvic and unpaired fins, and general body shape are found to resemble those of the Holocephali.

5. It is concluded that the Cochliodonts are almost certainly closely related to the ancestors of the Holocephali, and the relatively unspecialized condition of the teeth gives support to the view that the holostylic condition of the jaws is primitive for the group. It is suggested that all the Bradyodonts were holostylic, that the hyomandibular may never have been suspensory, and that they may have diverged from the true Selachii before the hyomandibular played a part in the jaw suspension. The difficulties which this view involves are appreciated.

6. The condition of the ethmoid region of *Helodus* supports the view of the nature of the ethmoidal canal put forward by De Beer and Moy-Thomas (1935) rather than that of Allis (1917, 1926, 1934).

EXPLANATION OF LETTERING OF TEXT-FIGURES.

ac = opening of aortic canal.
ag = groove for aorta.
alj = articular surface for lower jaw.
ar = anterior fused radials.
bpt = basipterygium.
cqp = cranio-quadrate passage.
de = dermal expansion of fin.
eps = foramen for the efferent pseudobranchial artery.
f = fenestrated part of neurocranium.
fm = foramen magnum.

hf = hypophysial foramen.
Hth = "Helodus" type of tooth.
hyp = foramen for the hypoglossal nerves.
lj = lower jaw.
lon = lamina orbito-nasalis.
mt = metapterygium.
ntf = notochordal foramen.
oc = occipital condyle.
ot = otic process of the palato-quadrate.
pop = preorbital process.
pro = propterygium.
Pth = "Pleuroplax" type of tooth.
pv = pelvic girdle.
ra = radials.
rnc = roof of nasal capsule.
ros1 ? = foramen by which ramus ophthalmicus superficialis? leaves skull.
ros2 = foramen by which ramus ophthalmicus superficialis passes from orbit to ethmoid part of skull.
IX = foramen for the glossopharyngeal nerve.
X = foramen for the vagus nerve.

EXPLANATION OF PLATES XIV AND XV.

Plate XIV.

Helodus simplex Ag. Palatal view of the skull. aoc = posterior opening of aortic canal, alj = articular surface for lower jaw, cqp = cranio-quadrate passage, epsb = foramen for efferent pseudobranchial artery, hyp = hypophysial foramen, otp = otic process of palatoquadrate, tth = tooth, IX = foramen for glossopharyngeal, X = foramen for vagus nerve. × 1½.

Plate XV.

Helodus simplex Ag. Fig. A, Lateral view of neurocranium with posterior part of palato-quadrate and preorbital process removed. f = fenestrated portion of the neurocranium, hyp = foramina for the hypoglossal nerves, lon = lamina orbito-nasalis, ros? = foramen for the ramus ophthalmicus superficialis ?, IX = foramen for glossopharyngeal nerve, X = foramen for vagus nerve. × 1⅔. Fig. B. Lateral view of left ramus of lower jaw. tth = tooth. × 1⅔. Fig. C, Lateral view of anterior part of skull without the palato-quadrate and preorbital process being removed. lon = lamina orbito-nasalis, ot = otic process of palato-quadrate, pop = preorbital process. × 2.

LIST OF LITERATURE CITED.

Allis, E. P., 1917. "The prechordal portion of the Chondrocranium of *Chimaera colliei*," *Proc. Zool. Soc. London*, p. 105.

—— 1926. "On the Homologies of the prechordal portion of the Skull of the Holocephali," *Journ. Anat.*, 60, p. 335.

—— 1934. "Concerning the Course of the Latero-sensory Canals in Recent Fishes, Prefishes, and Necturus," *Journ. Anat.*, 68, p. 361.

Bolton, H., 1905. "Palaeontology of the Lancashire Coal Measures. Pt. 1, Middle Coal Measures," *Trans. Manchester Geol. Soc.*, 28, p. 578.

Davis, J., 1879. "Notes on *Pleurodon affinis* sp. ined. Agassiz and Description of three Spines of Cestraciodonts from the Lower Coal Measures," *Quart. Journ. Geol. Soc.*, 34, p. 181.

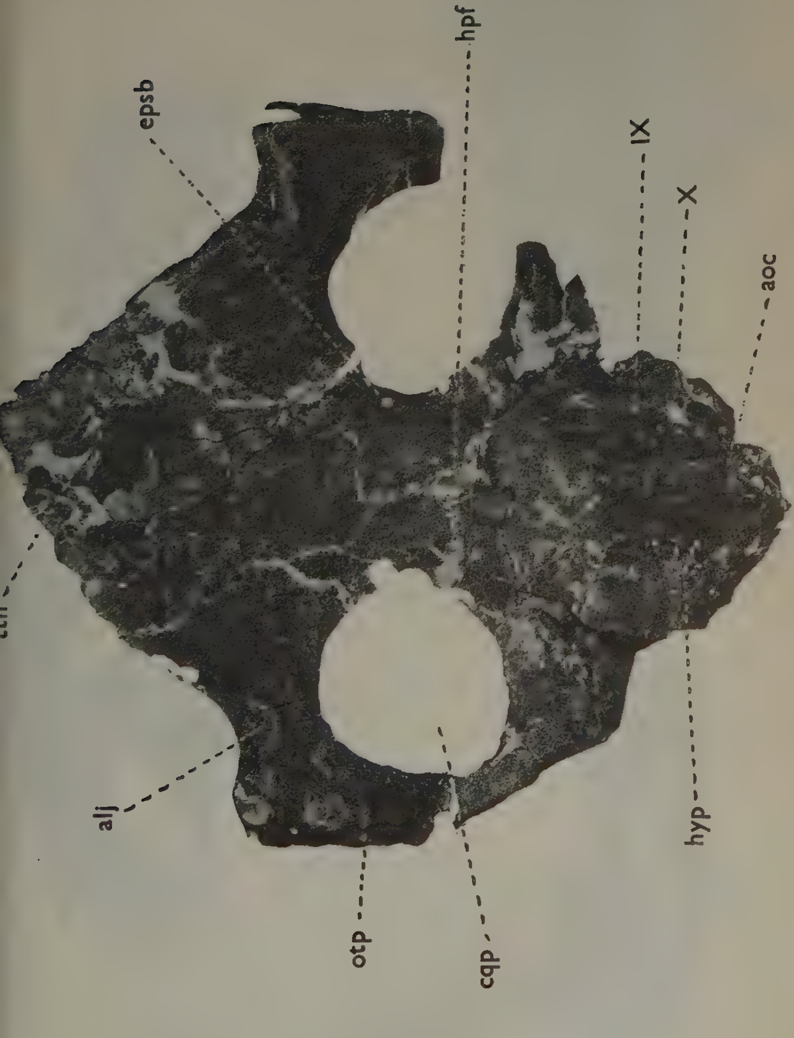
—— 1883. "On the Fossil Fishes of the Carboniferous Limestone Series of Great Britain," *Trans. Roy. Soc. Dublin*, ser. 2, vol. 1, p. 410.

—— 1890. "On the dentition of *Pleuroplax* (*Pleurodus*) A. S. Woodward," *Ann. Mag. Nat. Hist.*, 5, ser. 6, p. 291.

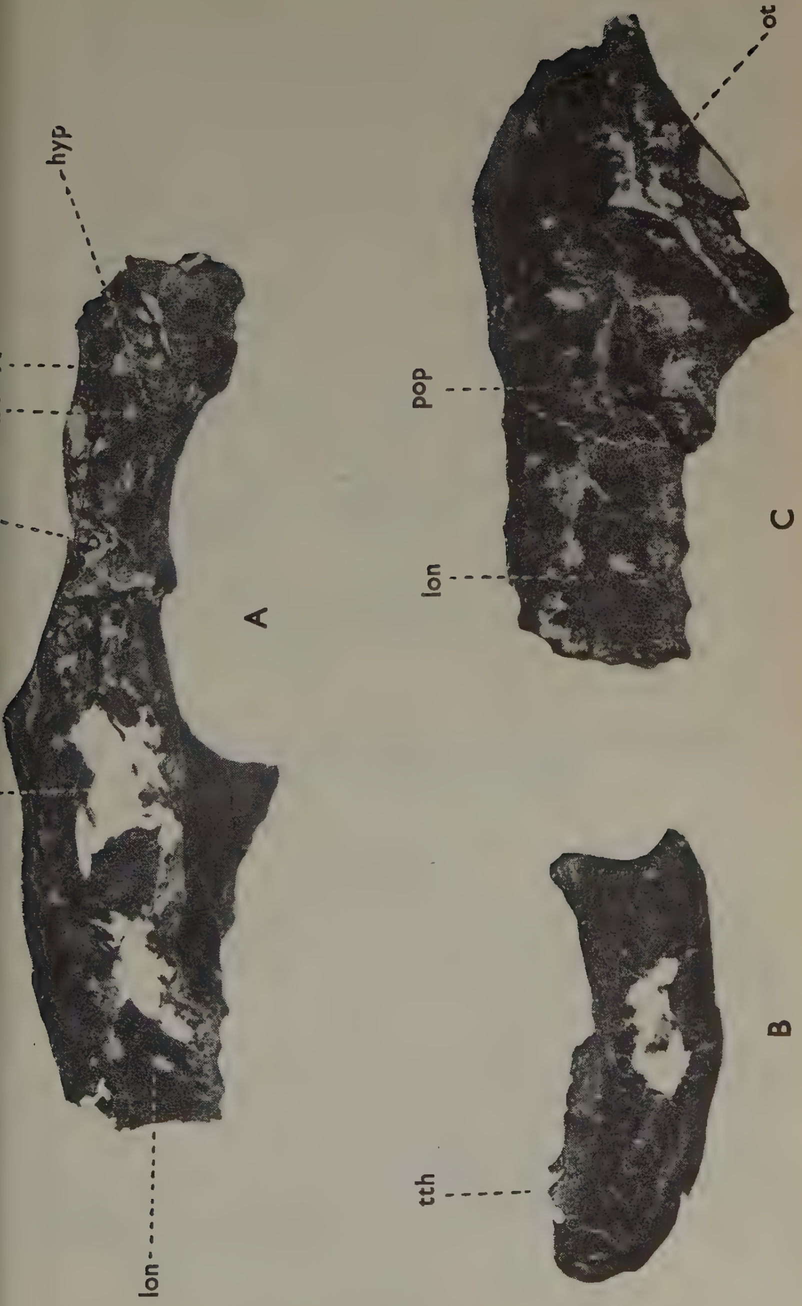
Dean, B., 1904. "In the Matter of the Permian Fish, *Menaspis*," *Amer. Geol.*, 34, p. 49.

De Beer, G. R., and Moy-Thomas, J. A., 1935. "On the Skull of Holocephali," *Phil. Trans. Roy. Soc.*, ser. B, 224, No. 514, p. 287.

Egerton, P. de M. G., 1872. "On *Prognathodus güntheri*, a new genus of Fossil Fish from the Lias of Lyme Regis," *Quart. Journ. Geol. Soc.*, 29, p. 232.



HELODUS SIMPLEX, Ag. PALATAL VIEW OF THE SKULL.



HELODUS SIMPLEX, Ag.

Gregory, W. K., 1904. "The Relations of the Anterior Visceral Arches to the Chondrocranium," *Biol. Bull.*, 7, p. 55.
Hancock, A., and Atthey, T., 1872. "Descriptive Notes on a nearly entire specimen of *Pleurodus Rankinei* . . . .," *Trans. Northumberland and Durham Nat. Hist. Soc.*, 4, p. 408.
Jaekel, O., 1891. "Ueber *Menaspis*, nebst allgemeinen Bemerkungen über die systematische stellung der Elasmobranchii," *Sitzber. Ges. Naturf. Freunde Berlin*, p. 115.
Moy-Thomas, J. A., 1935. "On the Structure and Affinities of *Chondrenchelys problematica*, Tr.," *Proc. Zool. Soc. London*, pt. 3, p. 391.
—— (In the press.) "The Structure and Affinities of the Fossil Elasmobranch Fishes from the Lower Carboniferous Rocks of Glencartholm, Eskdale," *Proc. Zool. Soc. London.*
Nielsen, E., 1932. "Permo-Carboniferous Fishes from East Greenland," *Medd. om Grönland*, 86, nr. 3.
Owen, R., 1840–5. "Odontography; or a Treatise on the Comparative Anatomy of Teeth, etc.," London.
Traquair, R. H., 1888. "Notes on Carboniferous Selachii," Geol. Mag., 35, p. 101.
Ward, J., 1875. "The Fossil Fishes of the North Staffordshire Coalfield," *Proc. N. Staffs. Inst. Mining Engineers.*
Weigelt, J., 1930. "Wichtige Fischreste aus dem Mansfelder Kupferschiefer," *Leopoldina*, 6, p. 601.
Woodward, A. S., 1889. "Catalogue of Fossil Fishes on the British Museum (Natural History)," pt. 1. Elasmobranchii, London.
—— 1898. "Outlines of Vertebrate Palaeontology," Cambridge.
—— 1915. "The Uses of Fossil Fishes in Stratigraphy," *Quart. Journ. Geol. Soc.*, 71.
—— 1921. "Observation on Some Extinct Elasmobranch Fishes," *Proc. Linn. Soc. London*, Session 133, p. 32.
—— 1932. "Text-book of Palaeontology," by Karl von Zittel, Second English edition. London.

Heavy Mineral Assemblages of Soils from the Goldfields of Western Australia.

By Dorothy Carroll.

Introduction.

A NUMBER of soil samples were collected from Kalgoorlie, Southern Cross, and other areas in the gold-bearing belt of Western Australia with a view to establishing the relationship between the "heavy" minerals of the soils and those of the parental material.

The interior of Western Australia consists of an extensive gently undulating peneplain of average height between 1,200 and 1,300 feet above sea-level. Soils largely obscure the underlying rocks which are of pre-Cambrian age. In the southern portion of the State wide areas are underlain by granites and gneisses, but greenstones and metamorphosed sediments are prominent. Gold is associated with the greenstones, usually, though by no means invariably, near a greenstone-granite contact.

The soils in each district were collected, as far as possible, from above the various rock types where these were exposed in railway cuttings, quarries, old shafts, and other similar places.

LABORATORY PROCEDURE.

For the mineralogical examination of soils it has been found that the "Fine Sand" grade is the most suitable for microscopic work. This grade, 0·2–0·02 mm. (the International Fine Sand of soil mechanical analysis adopted by agricultural workers), was obtained by sieving and elutriation with an Andrews' Kinetic Elutriator.

As the Fine Sands were brown to deep reddish-brown in colour it was necessary to remove this coating by boiling a minute or two in fairly strong hydrochloric acid before separating the "heavy" minerals with bromoform. The amount of this fraction was found by weighing the material before and after the bromoform separation. A magnetic fraction was found for a number of the fine sands.

In order to indicate the relationship between soils and underlying rocks the accessory minerals of the rocks from each area were obtained from type specimens.

The grains were mounted and identified by the usual optical methods, and for each heavy residue traverses (across the mounts) were made and the number of each species present noted. Particular attention was paid to the *varietal* features of the residual grains.

The percentage compositions of some of the residues are tabulated as frequency figures following the usage of the Burmah Oil Company[1] (1933).

THE SOILS FROM KALGOORLIE.

Kalgoorlie is situated 375 miles east of Perth at a height of 1,250 feet above sea-level. Practically the only topographic feature is a low ridge, east of the town, running more or less north-north-west and south-south-east, at the southern end of which is Boulder and the "Golden Mile", 3 miles from Kalgoorlie.

The rocks of the district belong to the greenstone and sedimentary series, the former being of economic importance. "Kalgoorlie differs from every other important gold-mining area in the State in that the main granite mass is far removed from the most productive mines" (Clarke, 1930).[2]

The mining area is made up of two series of greenstones invaded by two series of porphyrites. Regional metamorphism of a low grade has caused a north-north-west–south-south-east foliation and the production of epidiorites from the original dolerites and lavas, while metasomatic metamorphism and hydrothermal and pneumatolytic alterations have been superimposed on the original changes. Pneumatolysis is responsible for the presence of gold, tellurides, tourmaline, and fuchsite.

---

[1] Evans, P., Hayman, R. J., Majeed, M. A., "Graphical Representations of Heavy Mineral Analyses," *Proc. World Petroleum Congress*, i, 1933, 251.

[2] Clarke, E. de C., Pres. Address, Section C, *Aust. and N. Zeal. Assoc. Adv. Sc.*, 1930.

A considerable part of this district is underlain by members of an old sedimentary series, the most conspicuous being the conglomerates. Shales and silty shales sometimes grading up to fine-grained sandstones are also known. In the field the soils were found to be of a uniform reddish-brown type belonging to Prescott's *Mallee Soil Group.*[1] These soils invariably contain calcium carbonate in the subsoil, and where the parent material is highly calcareous, travertine or cement layers are formed. The natural vegetation gives some indication of the nature of the underlying rock, but, in general, there are few differences in the appearances of these soils. Laterite, here ironstone gravels and hard cappings of ferruginous and aluminous material, is conspicuous in parts of this district.

The Heavy Residues.—The heavy mineral assemblages were found to consist of the following species: Opaque black, yellow and red grains (ilmenite, magnetite, leucoxene, and limonite), amphiboles, epidote, zoisite, rutile, tourmaline, sphene, pyrite, biotite, white mica, chlorite, fuchsite, zircon, carbonates, andalusite, garnet, and gold. Of these, the opaque grains generally make up the bulk of the heavy residues, but are more abundant in the surface soils than in the subsoils.

Amphibole grains are of universal occurrence in these soils. In general, they are fibrous in habit, and either green or almost colourless. The green grains range from grass-green to bright bluish green, the latter being strongly pleochroic. The mean refractive index (for green) is about 1·63, and the pleochroism scheme is $Z =$ bright bluish green, X and $Y =$ green, $Z \wedge c = 21\text{–}25°$. The birefringence is low. Inclusions of small sphenes and iron ores are often present. In the colourless variety the extinction angle is often very small, and the refractive index rather less than for the green grains. Chloritized or micaized grains are common to those soils collected immediately above the greenstones, and occasional grains of unaltered brownish amphibole were also found. The general appearance of the amphibole grains in the heavy residues indicates that they are of local origin, and are residual from the weathering of the greenstones.

Epidote and zoisite are commonly present in the residues, the latter being the more plentiful. Epidote is usually "chunky" in appearance, but the zoisite is often prismatic, especially when near an outcrop of greenstone.

---

[1] Prescott, J. A., "Soils of Australia in Relation to Vegetation and Climate," *C.S.I.R.* (*Aust.*), Bull. 52, 1931, 59.

KALGOORLIE SOILS: COMPOSITION OF THE HEAVY RESIDUES.

Soil overlying	YG.	FCQ.	OG.	YG.	YG.	S.	P.	OG.	P.	YG.	OG.	TC.
Sample No.	20	33	36	12	17	55	46	49	61	59	23	64
Opaque black	7+	7	7	7	6+	7+	7+	7−	7−	6	7+	7
Opaque yellow to red	6	5	6+	7	7+	5	5	4	6−	6	6	7−
Leucoxene	3	5	3	2	4	5	6−	4	5	5	3	5
Pyrite	1	6			1*	1			7−	7		
Amphibole green	2	3	5	3	3	5	5	7	4	2	5	4
Amphibole colourless	1	1*	4	2	5	4	4	2	3	3	5	3
Epidote	1	1	*2	1		1	1	2	1	1	1	1
Zoisite	1		4	2	2	3	3	5	4	2	2	4
Rutile	3	5	4	2	1	3	4	3	3	1	1	3
Tourmaline	6	1	4	3	2	1	3	2	3	2	4	1
Sphene		2	1	1	1	1	1	1	1	1	2	1
Zircon	1	2	3	1	1	2	2	1	1	1	1	1
Micas	1			1*					1			
Fuchsite		6−										
Andalusite	2	1	2	1		2	2	1	3	1	3	2
Carbonate										3		
Chlorite										2		
†Heavy fraction, %	15	11	15	22	18	16	14	14	21	23	17	9
†Magnetic fraction, %	3·4	1·2	3·5	2·3	2·1	3·9	4·1	4·7	4·1	5·6	3·6	2·5

† Per cent by weight in fine sand.

YG. = Younger greenstone, FCQ. = Fuchsite-carbonate-quartz rock, OG. = Older greenstone, S. = Sediment, P. = Porphyrite, TC. = Talc-chlorite-carbonate rock.

Frequency No.	*Approx. %.*	*Frequency No.*	*Approx. %.*
8+	90–100	6−	14–17
8	74–89	5	7–13
8−	60–73	4	4–6
7+	45–59	3	2–3
7	35–44	2	1–2
7−	28–34	1	½–1
6+	23–27	1*	one grain only.
6	18–22		

Rutile is polyvarietal, and occurs in three main types :—

(*a*) Yellowish-brown and resin-coloured prismatic grains.
(*b*) Yellow irregular grains and prisms.
(*c*) Geniculate and arrow-head twins, and crystal aggregates.

These types are common to the rocks of the area. Occasional small, rounded, deep red to reddish-brown grains are thought to be "foreign" to the assemblage in that they are not known in any of the greenstones of the district; their source may lie in the sedimentary series. The pale coloured grains were formed authigenically in the greenstones during metamorphism.

Tourmaline, formed pneumatolytically during vein alteration, as already mentioned, is a common constituent of these residues. Dark bluish grey and brown grains are the ones most commonly found. There are very few rounded grains, the majority having sharp, prismatic faces. One or two of the soils contained large percentages of this species.

Sphene occurs in small "chunky" colourless to pale brown grains. It is nearly always present, but never in conspicuous amounts.

Pyrite makes up an appreciable part of some of the heavy residues from Boulder. It occurs in well-crystallized brassy cubes and combinations of cubes and octahedra. The arid climate and limy nature of these soils doubtless allows this species to remain, whereas in a moist climate it would disappear.

Gold.—Occasional small grains of this mineral were found in the residues which contained pyrite. The grains have dull, somewhat rounded surfaces. Gold was only found in the residues of soils collected from near a known lode.

Micaceous grains were conspicuous in some of the residues. Chlorite and white mica, probably sericite, were more plentiful than brown mica, while fuchsite was recorded from a subsoil above a fuchsite-bearing rock. These micas tend to disappear in the surface soils though often plentiful in the subsoils.

Zircon is almost universally present. The varietal features of this species are interesting, for a large number of types were found.

(*a*) Small, rounded, prismatic grains, non-zoned; some are almost equidimensional, others somewhat elongated.

(*b*) Zoned grains, usually rather elongated, but may be stumpy; often dusky or rather dense in appearance.

(*c*) Clear prismatic grains, sometimes with inclusions, occasionally large and squat.

Of these, (*a*) have the widest distribution. The grains are of a worn appearance and have evidently come from some pre-existing rock which may be now incorporated in the greenstone complex. The zoned grains are known to occur in the sedimentary series associated with the porphyrites, and are of wide distribution. The clear prismatic grains probably also come from these sediments.

Andalusite grains are often found in the heavy residues. No source is at present known for this species, but the shales associated with the intrusive porphyry are suspected. (Insufficient material was available for study to establish the "home" of andalusite.)

Garnet.—In one or two of the residues small colourless grains of garnet were found. It is apparently released on disintegration of the gritty bands found in some of the porphyrites.

Carbonate grains are plentiful in some soils, and are conspicuous in those greenstones which have suffered vein alteration.

Mineralogically the soils from Kalgoorlie are all rather similar, but there are several points of interest such as the notably higher percentages of rutile, tourmaline, and zoisite contained in the residues from soils formed over the older Greenstone series; the abundant polyvarietal rutile in soils from the talc-chlorite-carbonate rocks; and the difference in mineralogy (the actual amount of heavy minerals present) between the surface and subsoils.

The heavy residues, with the omission of andalusite, are what one would expect from country rocks of this type of greenstone.

The majority of the soils have arisen in situ and are not the result of drifting of weathered rock material.

Soils from Southern Cross.

Southern Cross, the centre of the Yilgarn Goldfield, is situated 237 miles east of Perth on the main line to Kalgoorlie. The topography is similar to that of most parts of the interior of Western Australia, and there are few prominent hills.

The rocks of the district fall into three main groups :—

(*a*) The *Greenstones* consisting of epidiorites and amphibole-schists, some of the latter being of sedimentary origin.

(*b*) The *Granites amd Gneisses* covering about three-fourths of the area. Some of the gneisses are of sedimentary origin.

(*c*) *Metamorphosed Sediments.*—Phyllites, slates, and schists. This group is considered to represent the oldest rocks in the State.

The *Soils* are somewhat similar to those of Kalgoorlie, but since there is a marked contrast in underlying rocks, this is nearly always reflected in the type of soil formed.

Southern Cross Soils : Composition of the Heavy Residues.

Soil overlying .	G.	G.	G.	G.	Gn.	Gn.	Gn.	S.	Gn.	Gn.	S.
Sample No. .	2*a*	6*a*	12191	12167	5*a*	8*a*	9*a*	86	12161	12182	12170
Opaque grains .	5	7+	4	6+	8	8−	7	7+	8−	7+	8
Amphiboles .	8	7	8+	8−	5	5	5	5	5	5	5
Zoisite . .	1*		1	2	1	2		1	1	1	
Epidote . .					1*	2			1	1	1
Rutile . .	1*	3	1*	1	1	1	2	5	2	4	1
Tourmaline .		1	1	1	2	2	3	6−	2	2	1
Zircon . .	1		1	1	4	3	3	3	3	2	2
Andalusite .				1*	3	4	6−	5	3	4	1
Garnet . .		1			1		3	1*	1	5	
Sphene . .			1	1*	1	3	4	1		1	
Monazite . .						1					
Kyanite . .					1*			1		1	
Biotite . .		1*	1			4	6−		1*		
Staurolite . .							1		1		
Sillimanite .							1	2	2	2	
†Heavy fraction, %			58	7					2	3	8
†Magnetic fraction, %			1·0	1·0					Tr.	Tr.	2·21

† Per cent by weight in fine sand.

G. = Greenstone, Gn. = Granite or Gneiss, S. = Sediment.

Frequency No.	*Approx.* %.	*Frequency No.*	*Approx.* %.
8+	90–100	6−	14–17
8	74–89	5	7–13
8−	60–73	4	4–6
7+	45–59	3	2–3
7	35–44	2	1–2
7−	28–34	1	½–1
6+	23–27	1*	one grain only.
6	18–22		

The soils from this district lend themselves admirably to an investigation such as this for several reasons :—

(1) There are three distinct series of rocks giving a contrast in the material available for soil formation.

(2) The surface of the country has very few steep hills, so that soil transport and creep are at a minimum.

(3) A considerable part of the country is in its original state, the natural vegetation having been interfered with only slightly.

The heavy mineral assemblages yielded the following species: magnetite, ilmenite, limonite, amphiboles, zoisite, epidote, pyroxene, rutile, zircon, sphene, anatase, tourmaline, apatite, andalusite, sillimanite, green spinel, kyanite, garnet, monazite, staurolite, chlorite, biotite, and muscovite.

Profile soil samples, showing the gradation from rock to soil, were obtained from a number of localities.

The Soils derived from Greenstones.—The rocks giving rise to these soils are metamorphosed basic igneous and basic sedimentary rocks, now epidiorites and amphibole-schists of various kinds. The main constituent of the heavy residues of these rocks was polyvarietal amphibole, often containing small black specks of iron ore, or colourless intergrowths of a micaceous mineral which has been referred to margarite. The heavy assemblages of the soils consist essentially of amphibole grains ranging in colour from almost colourless with a small extinction angle, to strongly blue-green with $Z \wedge c = 18\text{–}25°$. The amphiboles of the fine sands are similar to those of the epidiorites and schists.

The actual percentage of amphibole in these residues appears to be important, as does the relationship between the amphibole and opaque grains and the rest of the assemblage. A greenstone soil, from this area, can be indicated thus :—

Amphiboles (+), opaques (—), epidote, and zoisite.

While a non-greenstone origin gives :—

Amphibole (—), opaques (+), and minor species prominent. Occasionally in these soils rutile becomes prominent, but it is never so conspicuous as in the Kalgoorlie soils. The few grains of tourmaline and garnet recorded from these residues have been regarded as extraneous, but in general, the lack of contamination and freedom from "foreign" species is remarkable.

The Soils from Granites and Gneisses.—The exact relationship between the granites and gneisses in this district is by no means distinct, but further field work by the Geological Survey (not yet available to the writer) has probably cleared this up considerably.

From the soil point of view the most useful results were obtained by considering the accessory minerals of the various types of rock, and there has been little attempt to differentiate between the soils derived from granites and those from gneisses. The assemblages were found to consist of ilmenite, magnetite, limonite, andalusite, garnet, tourmaline, zircon, rutile, amphibole, epidote, zoisite, biotite, and sometimes a little sillimanite and kyanite. Of these, garnet, tourmaline, and zircon are polyvarietal, and often characteristic of a particular kind of parent rock. It is interesting to note that while apatite and biotite are prominent constituents of the gneisses they are unstable and fail to influence the character of the assemblages as much as would be expected from a study of the residues of the granites and gneisses. Garnet is widespread in the district and is known from phyllites, gneisses, and pegmatites. There are several varieties. Rutile is sometimes conspicuous, one gneiss containing an abundance of pale yellowish-brown grains. It is never prominent in the greenstones as at Kalgoorlie.

At first sight some of the heavy mineral residues may appear to resemble those from the greenstone soils, but there are several important differences :—

(1) The total amount of heavy residue is usually less than for soils derived from greenstones.

(2) The number of species is nearly always greater.

(3) Such minerals as tourmaline, zircon, rutile, and andalusite, garnet, and mica are often conspicuous.

Soils overlying the Sedimentary Series.—The sediments vary considerably in composition, and some of the gneisses are definitely of sedimentary origin. The residues of soils overlying slaty rocks yielded rather a disappointing assemblage, but the same type of zircon was found in the soils and parent material. One type of sediment is a fine-grained micaceous rock. The soils above this rock yielded large amounts of polyvarietal rutile, andalusite, and zircon, with tourmaline also noticeable.

The relationship between the soils and the sedimentary rocks thus appears clear, but a greater number of samples are required to bring this part of the investigation into line with the preceding part.

The amphibole grains liberated by the weathering of the greenstones are very persistent and tend to obscure the identity of non-greenstone soils near a contact. The smaller amount of heavy residue may here give a clue to such mixing.

Soils from other Districts.—The soils from above greenstones and other rocks were collected at a number of localities between Kalgoorlie and Leonora (150 miles to the north), and on examination of the heavy residues it was found that generally the "greenstone assemblage", on account of the persistent amphibole grains, could be distinguished from that of the non-greenstone. Often characteristic species were found in both rocks and soils.

CONCLUSIONS.

From a consideration of the tabulated percentage compositions, the varietal features of the species of the heavy residues, and the mineralogical composition of the country rocks, the following conclusions appear to be justified :—

(1) The character of the heavy residue of a soil will often give a clear indication of the nature of the parent rock. The diagnostic value of the assemblage is enhanced by the total amount of heavy residue in the fine sand, the amount of magnetic material and any distinctive features of the constituent species, e.g. polyvarietalism of rutile, zircon, and garnet.

(2) The residues indicate that in practically every locality examined the soils have been formed in situ by the weathering of the underlying rocks.

(3) There is a well-marked surface accumulation of residual grains in the Kalgoorlie soils, and in soils from other districts where the geology is similar. The subsoils contain chlorites and white mica which do not persist at the surface, where quartzose material accumulates at the expense of clay material.

In following up this investigation difficulty may arise in many districts in Western Australia (and this would be equally true for other countries) owing to the presence of deep leads and old drainage channels which are often concealed by drifted soil material. The heavy mineral residues of such soils will necessarily be of mixed origin, the assemblages yielding no definite information, except indirectly from such species as amphibole, rutile, tourmaline, and zircon.

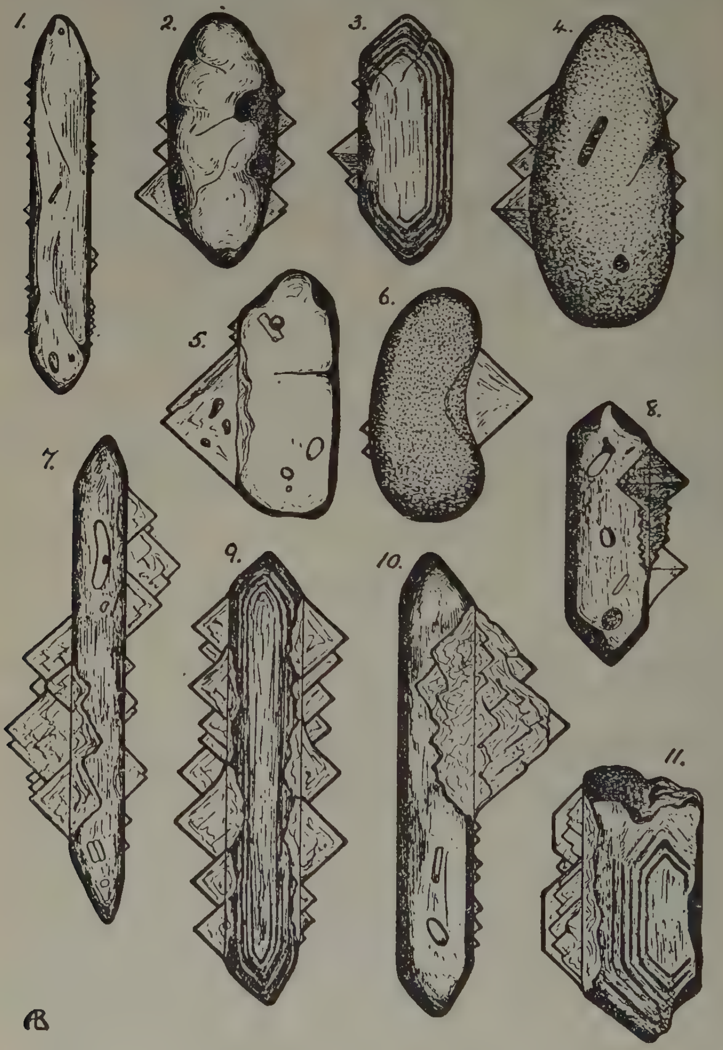
The results also indicate that it is necessary to investigate the mineralogy of the country rocks of any area in order to realize the significance of the heavy residues, and this would be the only way in which a similar investigation could be applied to assist the mapping in areas where there are few rock exposures.

Outgrowths on Zircon.

By J. A. Butterfield.

WHILST working through a batch of slides of heavy minerals of the Millstone Grit of the Pennine region some interesting outgrowths on zircon have been noticed which are worthy of record. The writer is not aware that they have been recorded before, but they must have a wider distribution than the Millstone Grit of this area, and therefore this mention of them may lead to further records being made known.

The outgrowths are observable on small zircons in mounted residues of heavy minerals and they take the form of small zircon pyramids growing out from the parent zircon as shown in the sketches in Text-fig. 1. As a general rule their growth seems to be from the prism faces (if present) of the parent zircon and their direction, in those noticed so far, is always at right angles to the principal axis of the original zircon. They are in complete optical continuity with the parent crystal. They vary considerably in size from the minutest tooth-like serrations fringing the side of the zircon and only visible by careful focusing with high power, to quite large outgrowths occasionally as large or larger than the pyramidal terminations of the parent crystal. In the former case they are usually numerous (see 1, Text-fig. 1), perhaps a score or more minute pyramids fringing one side of the crystal, although often only a single minute pyramid is seen attached to a large zircon crystal. In the case of the large outgrowths they are fewer and restricted to one or two regions on the



Text-fig. 1.

parent crystal face (see 5 and 6, Text-fig. 1). Between these two limits there is a complete gradation of sizes. Often crystals carrying large outgrowths also possess a complement of smaller outgrowths

EXPLANATION OF TEXT-FIG. 1.

1. Midgley Grit (Middle Grits). Subangular. Colourless. Outgrowths incipient. Length of zircon 0·35 mm.
2. Midgley Grit. Rounded. Colourless. Outgrowths of medium size. Length of zircon 0·24 mm.
3. Midgley Grit. Zoned. Subangular. Colourless. Outgrowths medium. Length of zircon 0·15 mm.
4. Upp. Kinderscout. Purple. Rounded. Outgrowths medium. Length of zircon 0·13 mm.
5. Upp. Kinderscout. Rounded. Colourless. Outgrowths large with few incipient. Inclusions in outgrowth. Length of zircon 0·14 mm.
6. Low. Kinderscout. Purple. Rounded. Outgrowths large with few incipient. Length of zircon 0·13 mm.
7. Upp. Kinderscout. Colourless. Subangular. Outgrowths medium. Length of zircon 0·14 mm.
8. Midgley Grit. Colourless. Subangular. Outgrowths medium and in different planes. Length of zircon 0·16 mm.
9. Upp. Kinderscout. Colourless. Zoned. Subangular. Outgrowths medium and shrouding original crystal. Length of zircon 0·15 mm.
10. Upp. Kinderscout. Colourless. Subangular. Outgrowths large with few incipient. Length of zircon 0·19 mm.
11. Midgley Grit. Colourless. Zoned. Broken. Outgrowths fusing to form zone of enlargement. Length of zircon 0·15 mm.

(see 6 and 10, Text-fig. 1). In rare cases the outgrowths have grown so closely and uniformly as to form a straight edge (see 11, Text-fig. 1). Occasionally they are so rampant as to form a complete shroud for the parent crystal, and in one or two doubtful cases the latter seems to be entirely surrounded by a complete envelope yielding what is to all appearances a complete secondary enlargement of the original crystal.

The actual dimensions of the individual outgrowths are exceedingly small. In the Millstone Grit of normal type almost the whole of the zircons pass through the 60-mesh sieve (0·2 mm.), and the great majority of them pass through the 120-mesh sieve (0·1 mm.). Therefore the majority of the zircons found in the mounted residues have a girth less than 0·2 mm. It is on such minute crystals that these outgrowths are found. After taking into account the greater relative abundance of the smaller zircons, it can be stated that about 10 per cent. of the outgrowths occur on zircons passing through the 60-mesh sieve, but stopped by the 120-mesh, and that about 90 per cent. occur on zircons passing through the 120-mesh sieve. The individual outgrowths on the large zircons are not necessarily any bigger than those on the small zircons. Indeed, it can be said that the size and nature of the outgrowths are entirely independent of the size and nature of the crystals to which they are attached. In the quantitative details given below the figures relate to zircons passing through the 120-mesh sieve.

The outgrowths are found attached to all types of zircons. Zircons with good crystal outline, subangular and rounded zircons, broken grains, purple, dusky, and yellow zircons, all carry their share of outgrowths. Whatever the type of zircon, however, to which the outgrowths are attached the latter are invariably perfectly sharp in outline and always water-clear and colourless. In shape they are obviously pyramids although it is exceedingly difficult to detect crystal faces in transmitted light, and it has not been possible to examine them with a binocular microscope in reflected light. Occasionally, however, there does appear to be evidence of four pyramid faces as suggested in 3, 4, and 8, Text-fig. 1. In one or two rare cases the outgrowths contain irregular inclusions of ferruginous material (see 5, Text-fig. 1), though this is unusual. Normally the outgrowths are beautifully clear and fresh without the slightest trace of rounding. They apparently occur at different planes on the crystal face, for in the case of the bunched groupings of outgrowths they are brought into focus at different stages as the microscope is racked up or down.

Zircons carrying these outgrowths have a wide range throughout the Millstone Grit both vertically and horizontally, though they are always few numerically. The following short analysis giving the result of an actual count of zircons carrying these outgrowths may be of interest.

For the purpose of the count 150 slides of mounted residues were selected at random. Each slide selected was of typical Millstone Grit material, and in each case the residues had been cleaned by boiling in dilute hydrochloric acid and were from material passed through the 120-mesh sieve. They represented the whole range of the Grits from the hard bands in the Sabden Shales to the top of the Rough Rock.

It will probably be of interest to those not familiar with heavy mineral work to note the comprehensive nature of such a study. It is computed that each slide of mounted residue contains on an average 5,000 heavy mineral grains. The 150 slides, therefore, would contain about 750,000 grains. Of the Millstone Grit heavy minerals passing through the 120-mesh sieve, after boiling in HCl, about one-third on the average are zircons, so that it can be assumed that in scanning through these 150 slides about 250,000 zircon grains would be passed over. Obviously many grains containing outgrowths must have been missed, but the count was made carefully and the result was that 584 grains were noted carrying these outgrowths. This gives the grains carrying outgrowths as 0·234 per cent. of the total number of zircons. It will be a slightly low estimate, but it indicates the rarity of the outgrowths. At the same time, out of the 150 slides examined the outgrowths were only absent in 5 slides, so that whilst rare the outgrowths are universally present. The average number of grains per slide worked out as follows :—

Rough Rock . . .	3·6 per slide.
Middle Grits . . .	5·5 per slide.
Kinderscout Grits, etc. .	3·4 per slide.

The distribution is therefore very regular. The slight preponderance in the Middle Grits is due to one horizon—the Midgley

Grit—in which these outgrowths are relatively very common. Slides of this material from near Huddersfield yield 20–30 examples of "zircons containing outgrowths" per slide.

In studying the distribution of the heavy minerals of the Grits it has been found expedient to divide the zircons into a number of well-marked types, and it is interesting to note the distribution of the outgrowths in relation to these types and also in relation to the three main subdivisions of the Grits. The following table shows this distribution, the outgrowth frequencies being given as percentages for each of the three Grit subdivisions and in relation to the zircon types.

Type of Zircon.	*Rough Rock.*	*Middle Grits.*	*Kinder-scout.*
Colourless.			
1. Good crystal outline	1	5	8
2. Subangular	27	16	31
3. Rounded	31	41	21
4. Zoned subangular	2	4	8
5. Zoned rounded	—	1	1
Total	66 per cent.		
Purple.			
1. Subangular	9	14	8
2. Rounded	17	7	11
3. Zoned	4	2	3
Total	25 per cent.		
Dusky.			
1. Subangular	3	2	2
2. Rounded	2	6	3
3. Zoned	—	1	3
Total	7 per cent.		
Yellow.			
1. Much worn	4	1	2
Total	2 per cent.		
	100%	100%	100%

A study of this table shows that the outgrowths are attached to all types of zircon. As the table stands, it would appear that the outgrowths are more often attached to the colourless zircons, especially the subangular and rounded types, but in this respect the table is misleading unless the relative numerical distribution of these types is taken into consideration. A count over a large number of slides gives the relative distribution of the main types of zircon passing through 120-mesh and arranged by colour as follows :—

Colourless zircons	67·5 per cent.
Purple zircons	10·5 ,,
Dusky zircons	12·0 ,,
Yellow zircons	10·0 ,,

By combining this information with the table above it will be seen that actually the purple zircons are carrying the biggest share of outgrowths. The suggestion also that the outgrowths are more commonly attached to rounded and subangular zircons, as indicated in the table, is also misleading, because here again these are the common zircons of the Grits. Actually the outgrowths are very evenly distributed throughout all types of zircons and in all the subdivisions of the Grit.

So far as the writer's work is concerned, these outgrowths are important because they are going to play a part in the study of the genesis of several of the heavy minerals of the Grit. The fact that they are always of perfect shape and unworn, and that they are attached as water-clear colourless outgrowths to rounded purple and yellow zircons suggests that they have been formed in the Grit since the deposition of the materials forming this rock. It is interesting to note in this connection that many of the zircons in the Grit show markedly etched surfaces. The writer would be pleased to hear of other occurrences of such outgrowths and observations as to their formation.

Cymatelasma, a new Genus of Silurian Rugose Corals.

By Dorothy Hill and A. J. Butler.

(PLATE XVI.)

THIS paper describes and discusses the affinities of a new genus of Rugose corals, and indicates the trends of development affecting it; the stratigraphical distribution of the four new species which compose the genus is recorded, and the structure, insertion, and symmetry of their septa are described in some detail.

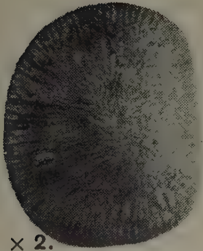
We are very grateful to Dr. W. D. Lang and Dr. Stanley Smith for reading our typescript, and for constructive criticism. One of us (D. H.) wishes to acknowledge indebtedness to the Royal Commission for the Exhibition of 1851 for the award of a Senior Studentship, during the tenure of which her part of the work was done; and the other (A. J. B.) to the Governing Body of Emmanuel College, Cambridge, for the award of the External Research Studentship for 1933.

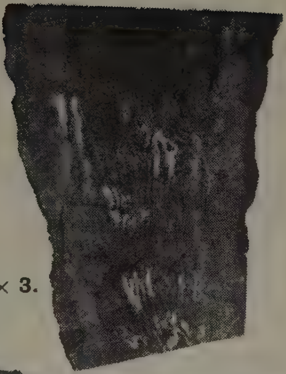
Cymatelasma, gen nov. (Pl. XVI, Figs. 1–17.)

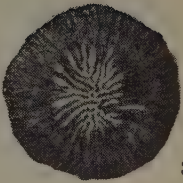
κῦμα, -ατος = wavy, and ἔλασμα = a plate (hence septum).

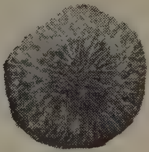
Genotype.—Cymatelasma corniculum sp. nov.; here described.

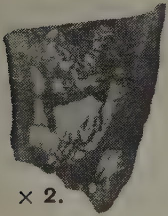
Diagnosis.—Simple rugose corals in which septal dilatation is very marked in early stages, but usually becomes progressively reduced from the axis outwards during ontogeny; a peripheral stereozone is present in the adult; the septa are waved parallel to their upper edges, and may develop carinae along the crests of the waves; the major septa are unequal in length, and the septal symmetry is like that of *Spongophylloides* Meyer. The tabulae are complete and inversely conical. There are no dissepiments.

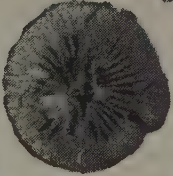

1. × 2.

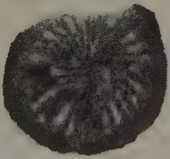

2. × 3.

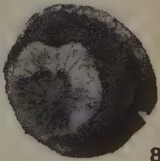

3. × 3

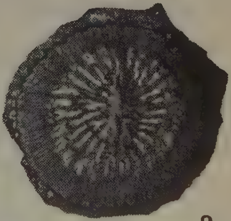

4. × 3.

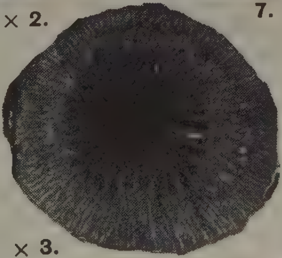

5. × 2.

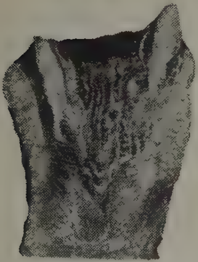

6. × 2.

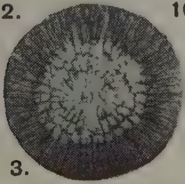

7. × 3.

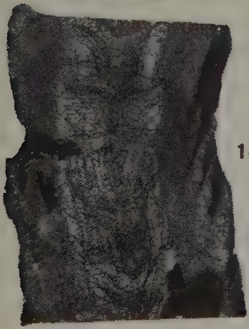

8. × 3

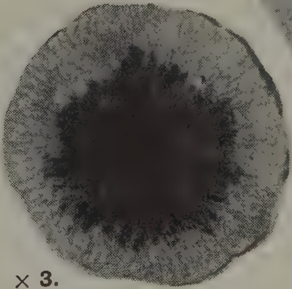

9. × 3.

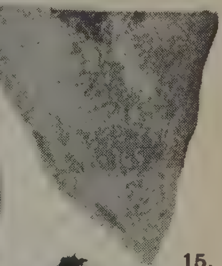

10. × 3.

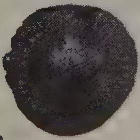

11. × 2.

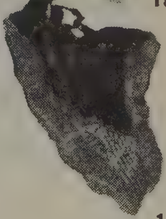

12. × 3.


13. × 3.


14. × 3.


15. × 3.


16. × 2.


17. × 2

Cymatelasma gen. nov.

Distribution.—Individuals are comparatively rare; we group our specimens into four species whose distribution is as follows: *C. multiseptatum,* from the base of that part of the Upper Llandovery exposed at the Dingle, between Worcester Beacon and the Sugar Loaf, Malverns; *C. corniculum*, from the Woolhope Limestone of Woolhope and May Hill; *C. carinatum*, from the Wenlock Limestone of Wenlock Edge, Dudley, and Walsall; and *C. tardens*, from the Lower Ludlow of Ledbury Quarry, Malverns. No specimens of *Cymatelasma* are yet known from the Wenlock Shale.

Cymatelasma multiseptatum sp. nov. (Pl. XVI, Fig. 1.)

Holotype.—Sedgwick Museum A 7760 [1] from the conglomerate at the base of that part of the Upper Llandovery exposed at the Dingle, between Worcester Beacon and the Sugar Loaf, Malverns; collected by the late Professor T. McKenny Hughes. This is the only specimen known.

Diagnosis.—Turbinate to trochoid *Cymatelasma*, with numerous wavy septa so dilated as to be laterally contiguous throughout and to fill the lumen.

Description.—The corallum is simple, turbinate, and curved at first but rapidly becomes regularly trochoid and erect, and compressed along the plane containing the cardinal and counter septa. It is 30 mm. long; the calice is conical, 33 mm. across its longest diameter, 20 mm. across the shortest diameter, and 12 mm. deep, and is divided by the very tall upper parts of the septa. The epitheca is weathered away, exposing the dilated contiguous bases of the septa.

The septa are dilated, 45 of each order, and laterally contiguous except in the calice, and are waved parallel to their upper edges. They are altered by recrystallization as described below in the section on septal structure, so that their true microscopic structure is masked. Text-figure 8 is a drawing of the recrystallized septa of *C. multiseptatum.*

The minor septa are very short. The major septa are arranged in four groups according to their length and curvature, two groups consisting of those near the cardinal and counter septa, and two of those remaining on each side. The counter septum is very long, and extends beyond the axis. The longer septa reach the axis, and in the younger stages are all curved, so that an axial vortex is formed. In the later stages this axis elongates to a plane which is slightly rotated with regard to the plane of the cardinal and counter septa. The septa in the cardinal and counter groups curve towards the ends of the elongated axis, but those of the two side groups are directed to points along it without curving except at their axial edges. The rotation of the septa and their inequality lessen as the calice is approached. The fossulae are not distinct. Very few interseptal loculi are present, owing to the extreme dilatation of the septa, and even when loculi occur tabulae and dissepiments are not known.

---

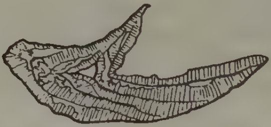
[1] All the specimens mentioned and figured in this paper are in the Sedgwick Museum, Cambridge.

Cymatelasma corniculum sp. nov. (Pl. XVI, Figs. 2–8.)

Type Material.—All from the Woolhope Limestone. *Holotype:* A 7761, new road cutting south of Stony Hill Farm, Woolhope. *Paratype:* A 7762, 7–10 feet above *Petalocrinus* bed, same locality; A 7763, 60–73 feet above *Petalocrinus* bed, same locality; and A 7767, Rudge Farm Quarry, Woolhope. *Other specimens:* A 7764–6, shale band at base of Woolhope Limestone, Canwood New Quarry, Woolhope; A 7768, Rudge Farm Quarry, Woolhope; A 7769–7771, Old Oaks Farm, May Hill. All collected by J. K. S. St. Joseph.

Diagnosis.—Regularly expanding, slightly curved, ceratoid *Cymatelasma*, typically with gently waved, non-carinate septa, and distant, dilated tabulae.

Description.—The corallum is simple, ceratoid, gently curved and regularly expanding. It may be flattened about the plane of the cardinal and counter septa. The average height is 20 mm., with a diameter at the calice of 9 mm. The largest specimen was 30 mm. long, with a calical diameter of 13 mm. The calice is 10 mm. deep and inversely conical, with septa projecting a considerable distance above its floor. The epitheca is not visible in any of the specimens, which are all coated with tufa.



TEXT-FIG. 1.—*C. corniculum* in median vertical section, showing the dilated, distant, inversely conical tabulae (A 7770 *b*).

The septa are of two orders, about 35 of each. They are waved; the waves run parallel to the upper edges of the septa, but do not bear carinae. Their structure, insertion, and symmetry is described below in a separate section. The minor septa are very short (maximum length 1·5 mm.); the major septa are very unequal in length and in distance apart, and often have narrow lobes directed upwards from their axial edges as in *Streptelasma* Hall. The dilatation of the septa is complete in the apical parts of the corallum, where they are laterally contiguous and fill the lumen. During ontogeny it decreases from the axis outwards, leaving a wide peripheral stereozone. When rejuvenescence occurs the dilatation again becomes extreme, and then again decreases from the axis outwards. At such periods of rejuvenescence tabulae occur. They are dilated, their tissue being continuous with that of the septa bounding them;

and they are distant, complete, and inversely conical (Text-fig. 1). No dissepiments are formed.

Cymatelasma carinatum sp. nov. (Pl. XVI, Figs. 9–13.)

Type Material.—Holotype, A 8360, from the top part of the Nodular Bed division of the Wenlock Limestone, old quarry opposite lime-kilns on the south-west of Wren's Nest Hill, Dudley, Worcs. *Paratypes*: A 7776, Wenlock Limestone, Lower Quarry, Stretton Westwood, Wenlock Edge, Salop; A 8355–8359, Basement Beds of the Lower Wenlock Limestone, Railway Cutting near Daw End, Walsall, Staffs. *Other specimens*: A 8363–4, Nodular Beds, Wenlock Limestone, Hurst Hill, East of Sedgeley, Staffs; A 5580, Wenlock Limestone, Stretton Westwood Quarry, Wenlock Edge; A 5581, Wren's Nest, Dudley; A 7777, Lilleshall Quarry, Wenlock Edge; A 7778–9, Farley Dingle, near Much Wenlock; A 7780, Bradley Farm, near Much Wenlock.

Diagnosis.—Cylindrical *Cymatelasma*, in which rejuvenescence is common, with highly carinate septa and closely set tabulae.

Description.—The corallum is cylindrical, curved cylindrical, or ceratoid, and is generally rendered irregular by frequent constrictions produced by cone-in-cone rejuvenescence. The septa stand out in strong relief in the calice, which is shallow and has gently sloping walls. An average specimen is 35 mm. in length, and has a calice 12 mm. in diameter and 5 mm. deep. The epitheca is thick, and bears well-marked septal grooves whose arrangement indicates the position of the cardinal and alar fossulae, and shows that the insertion of new septa takes place at the usual four points.

In the adult stages there are from 26 to 36 major septa, extending from the epitheca nearly to the axis, and arranged in a pattern which is characteristic of the genus, described below. They alternate with an equal number of minor septa whose length is about one-third to one-half of the radius of the lumen, with the exception of the two minor septa flanking the counter septum, which are longer and may extend almost to the axis. Both cycles of septa are much dilated near the periphery, where they are contiguous and form a peripheral stereozone equal in width to about one-third of the radius of the lumen, but taper towards the axis. They bear strongly developed carinae, which lie parallel to their upper edges (see Text-fig. 5); these carinae, which are diagnostic of the species, are best seen in longitudinal sections. (Pl. XVI, Figs. 11, 13.)

The tabulae are complete, inversely conical, regular, thin, and closely set. There are no dissepiments.

Ontogeny.—In the earliest stages of development the septa are dilated throughout their length; during ontogeny a progressive reduction of dilatation from the axis towards the periphery is correlated with the development of tabulae and carinae. Rejuvenescence is accompanied by an increase in septal dilatation and hence by an increase in the width of the peripheral stereozone.

Variation.—Two specimens from the Wenlock Limestone of Wenlock Edge are abnormal, in that excessive septal dilatation, preventing development of tabulae (but not of carinae) persists throughout the greater part of ontogeny.

Cymatelasma tardens sp. nov. (Pl. XVI, Figs. 14–17.)

Type. Material.—From the Lower Ludlow Shales of Ledbury Quarry Tip, Malverns. *Holotype:* A 7772; *Paratypes:* A 7774 and 7775. *Another specimen*, A 7773, same locality. Collected by Miss F. E. S. Caldwell (Mrs. N. S. Alexander).

Diagnosis.—Slenderly trochoid, gently curved *Cymatelasma*, with zigzag and carinate septa dilated and laterally contiguous except just below the axis of the calice, and with distant tabulae.

Description.—The corallum is simple, slenderly trochoid, and gently curved, attaining a maximum diameter of 16 mm. in a maximum height of 20 mm., with a calical depth of 11 mm. The average corallum is somewhat smaller. Rejuvenescence is rare and is of the cone-in-cone type. The epitheca shows well-rounded interseptal ridges and narrow septal grooves. Transverse striation is faintly marked.

The septa are of two orders, about 38 of each order, and are so dilated as to be laterally contiguous and thus to fill the lumen,

SUMMARY OF DIAGNOSTIC CHARACTERS OF SPECIES OF CYMATELASMA.

	Corallum	Septal dilatation	Carinae	Tabulae
C. multiseptatum	Turbinate or trochoid.	Great. Septa laterally contiguous throughout ontogeny.	None.	None.
C. corniculum	Typically ceratoid.	Septa contiguous in early stages. Decrease in dilatation from axis outwards during ontogeny. Peripheral stereozone in adult.	None, but septa are waved parallel to their distal edges.	Distant and dilated.
C. carinatum.	Typically cylindrical.	As in *C. corniculum*, but reduction of dilatation more rapid, and stereozone in adult usually narrower.	Strongly developed.	Closely set, thin, and regular.
C. tardens	Curved trochoid	Septa dilated and contiguous through greater part of ontogeny.	Well developed.	Distant and dilated.

except just below the axis of the calice. They are zigzag, and strongly carinate, the carinae being parallel to the upper edges of the septa. This is well seen in the calice, but in the lumen the great dilatation masks the carinae, which can be observed only because recrystallization has had a different effect on the inner and outer parts of the septa, as described in the section on the septal structure of the genus. The inner parts, whose fibres were laid down along the crest of the septal invagination in the base of the polyp, appear as a light-coloured lane whose zigzag course and carination can be seen under crossed nicols. The structure, insertion, and symmetry of the septa is that described below as typical of the genus.

Some of the septa show delicate lobes at their axial edges like the septa of *Streptelasma*, and others have parts of their axial edges slightly swollen. The minor septa are short and buried in a wide peripheral stereozone. The tabulae are dilated, distant, and inversely conical. There are no dissepiments.

TRENDS OF DEVELOPMENT.

Without making any assumptions as to the precise interrelations of the species, it would seem that during Silurian times *Cymatelasma* was evolving as follows: Change of shape from turbinate to cylindrical; increase in rejuvenescence; reduction of dilatation of skeletal elements; elaboration of the septa; and increase in number of the tabulae. These are exactly the changes found by one of us (D.H.) affecting the Acanthocyclidae in the same area at the same time. In *Cymatelasma* the trend towards elaboration of the septa ends in the formation of carinae running along the sides of the septa parallel to the upper edge of the septa. These carinae possibly assist the tabulae in carrying out the functions of horizontal skeletal elements.

The *Cymatelasma* from the Lower Ludlow shale of Ledbury Quarry (*C. tardens*), like the Acanthocyclidae from the same place, are interesting in that they have developed less along the trends of shape change, reduction of dilatation, and degree of rejuvenescence than the Wenlock Limestone species of Shropshire and the Midlands, although in elaboration of the septa and number of tabulae they are just as far advanced. This backwardness may be correlated with facies—the muddy waters of the Ludlow shales being less favourable for development of certain structural elements than the clearer waters of Wenlock Limestone times. Or it may be due to isolation of the Ledbury area from the Shropshire and Midlands, where perhaps evolution was quicker. A further possibility is that authors have been mistaken in assigning the lower shales of Ledbury Quarry to a horizon above the Wenlock Limestone of Wenlock Edge.

As to relations between the species, it seems reasonable to suggest that *C. carinatum* was derived from *C. corniculum*, and that the latter probably descended from *C. multiseptatum*. *C. tardens* may have been derived directly from *C. corniculum*.

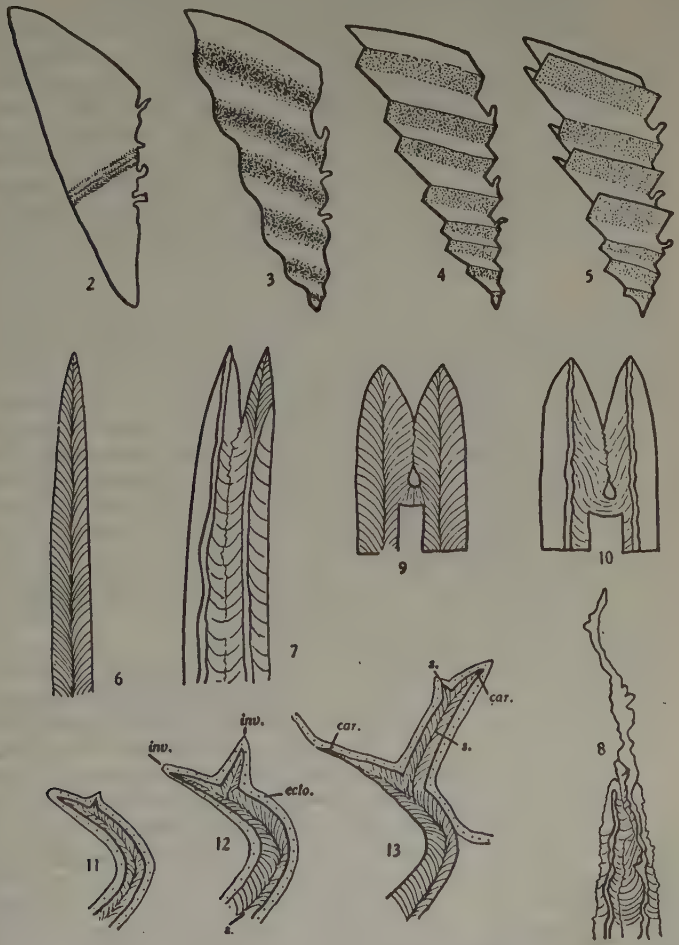
AFFINITIES OF THE GENUS.

The origins of the genus are still unsettled. Possibly it was derived from *Streptelasma* Hall. This is suggested by the way in which dilatation of the septa decreases from the axis outwards during ontogeny, leaving a peripheral stereozone; by the tendency for the septa to have denticulate axial edges as in *Streptelasma*, and by the absence of dissepiments. But the tabulae of *Streptelasma* are domed and numerous, while in *Cymatelasma* they are inversely conical and infrequent; and in *Streptelasma* wavy and carinate septa are not known. The genus is undoubtedly closely related to *Spongophylloides* Meyer, to which it may have given rise by the increase in length of the minor septa and the development of dissepiments. The structure, insertion, and symmetry of the septa, and the nature of the tabulae is identical in the two genera, and cone-in-cone rejuvenescence is frequent in both. Except for its dissepimentarium the species *Spongophylloides pusillus* Butler is often morphologically identical with *C. carinatum*.

SEPTAL STRUCTURE (D. H.) (Text-figs. 2–13.)

The septum in *Cymatelasma* is a continuous vertical plate, always more or less dilated; it sometimes has its axial edge divided into slender lobes directed steeply up towards the axis (Text-figs. 2–5), in a manner known otherwise only in *Streptelasma*. The upper edge slopes from the epitheca to the axis in a regular shallow curve, which may be either concave or convex. In the Lower Llandovery-Woolhope individuals the septa are waved, the crests of the waves running along the sides of the septum, parallel to its upper edge (Text-fig. 3). In the Wenlock and Ludlow species the wave length is very short, the crests become angular (Text-fig. 4), and thin carinae grow out from them (Text-fig. 5).

Septa whose intimate structure is not masked by recrystallization are seen only in *C. corniculum*, and that rarely. Such septa are seen each to consist of a number of fibrous trabeculae (Text-fig. 2), similar to the trabeculae of *Heliopora* as described by Bourne, and arranged in single series approximately along the median plane. But in *C. corniculum* each trabecula is directed upward and inward approximately at right angles to the epitheca; each extends from one side of the septum to the other, but the axes of neighbours are only 0·2 mm. apart, so that the trabecula is rectangular in transverse section. The fibres of a trabecula are directed pinnately upwards and outwards from the axis. They are almost vertical at the axis, but curve gently to cut the sides of the septum (as seen in transverse section of the corallum) at about 60 degrees (Text-fig. 6). The vertical plane containing the axes of the trabeculae appears as a median dark line in transverse and tangential vertical section of the corallum. Many of the specimens of *C. corniculum* are slightly altered by weathering, and their sclerenchyme looks powdery in thin section, the course of the fibres being thus masked. Recrystallization has characteristic effects on the septa of the genus, effects similar to those seen in *Pycnactis mitratus*, which has an almost identical arrangement of the fibres. Owing to this recrystallization each dilated



Text-figs. 2–13.—*Septal Structure.* 2–5 : Diagrams showing the derivation of a carinate septem (5) from a plane septum (2) through a wavy septum (3), and a zigzag septum (4). In fig. 2 two trabeculae are drawn in median vertical section. 6, 7 : Diagrams to show (6) an unaltered pinnately fibrous septum, as in *Pycnatis mitratus* (Schlot) and the appearance of two such septa (7) after recrystallization (see text). 8 : Recrystallized septa in *C. multiseptatum.* 9, 10 : Diagrams to show the relation of the tissue of a dilated tabula to the neighbouring septa ; 9, unaltered ; 10, recrystallized (see text). 11–13 : Diagrams showing the formation of a carina. s. = septum ; ecto. = ectoderm ; inv. = invagination ; car. = carina.

septum appears to consist of an inner and an outer part. The inner part is thin and appears at first sight to be the whole septum; in early descriptions it might easily have been referred to as the " primary septum ". The outer parts of the septa appear at first sight to be a sort of groundmass of sclerenchyme in which these " primary septa " are set (Text-fig. 7). Thus that part of the middle of the septum where the fibres run almost vertically (i.e. parallel to the plane of the septum) is usually seen as a lane (" the primary septum ") bounded on each side by a shadow, and sometimes opening out towards the axial end of the septum (Text-fig. 7). In a completely dilated septum, if the original course of the septal invagination was wavy or zigzag, this lane will be wavy or zigzag (Text-fig. 8). Sometimes parts of the lane are recrystallized into a single rod-like crystal. The outer portions of the septum may be affected in two ways; in the commoner way all structure is destroyed; under high powers of the microscope brighter and darker patches indicate the areas where large crystals are beginning to form[1]; in the second a lamellation is induced at right angles to the direction of the fibres (Text-fig. 7); it follows the original growth lamellae of the thick sclerenchyme, and has exactly the appearance of the lamellar sclerenchyme in *Acanthocyclus*, *Tryplasma*, and *Cystiphyllum*. Were it not for a fine irregular line, which may with care be distinguished between two septa, it would seem as if outer parts of the dilated septa were dilated horizontal tissue laid down between the " primary septa ".

When dilated tabulae occur they are seen to consist of fibres at right-angles to their surfaces, and to be continuous with the tissue dilating their bounding septa (Text-figs. 9, 10).

Formation of a Septum (Text-figs. 11–13). The septum began to form in small conical invaginations in the base of the polyp, arranged approximately 0·02 mm. apart in a radial series. In each conical invagination a trabecula was begun. As deposition of fibres proceeded, neighbouring trabeculae coalesced to form a lamellar septum, and caused a radial invagination on the base of the polyp, which grew in height as the septum grew. The ectoderm of the sides of this invagination deposited fibres on the sides of the trabeculae, continuous with the fibres of the trabeculae, so that the septum dilated. Dilatation of the septum ceased when two neighbours killed the fold of polypal or ectodermal tissue between them by compression, or when this fold was withdrawn higher into the corallum to relieve stresses caused in the base of the polyp by the upward growth of the septa. In the latter case the fold deposited part of a tabula below its new position of rest. The ectoderm of the sides of the neighbouring septal invagination would be continuous with the ectoderm of the fold, and so the tissue of the tabula or dissepiment was continuous with that dilating those parts of the septa above it.

---

[1] I am much indebted to Dr. Maurice Black for instructing me in the effects of re-crystallization in a fibrous aggregate. (D. H.)

The waving of the septum parallel to its upper edge must have been caused by periodic changes in the inclination of the normally vertical septal invagination. When the crests of the waves became angular a new invagination developed on the upper surface of the inclined invagination, and continued the upward growth of the septum. The old invagination continued to secrete for a little time, and formed a carina. That these carinae are thus formed in an inclined septal invagination and not by the fold of polypal tissue between two septa is proved by the fact that they consist of fibres laid down on either side of a median dark line. Horizontal skeletal elements have their fibres deposited from only one surface of ectoderm.

Other genera with similar carinae are *Spongophylloides* Meyer from the Silurian of Europe; *Lopholasma* Simpson, from the Hamilton (Middle Devonian) of Western New York, which was possibly derived from *Streptelasma* Hall; and *Lophocarinophyllum* Grabau, from the Upper Carboniferous of China.

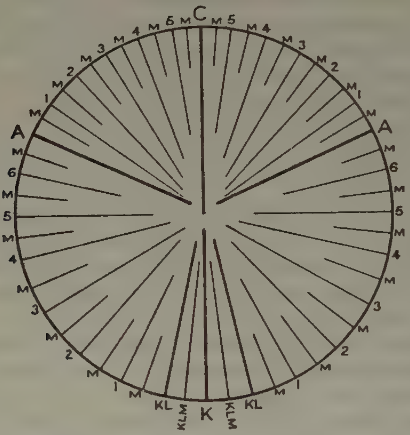
Septal Insertion and Symmetry.—Insertion: Examination of serial transverse sections, supported by the arrangement of the septal grooves on the epitheca, shows that the metasepta in *Cymatelasma* are inserted at the usual four points, i.e. on each side of the cardinal septum and at the alar fossulae. *Cymatelasma* belongs to the large group of rugose corals whose mode of septal insertion conforms with that in *Zaphrentis*, and not with the mode in *Petraia*[1]; but, as in several other Silurian genera,[2] the *Zaphrentis* mode is slightly modified in *Cymatelasma* in that two minor septa flanking the counter septum appear earlier and subsequently grow to a much greater length than the remainder of the minor septa, which appear as a "crop" after several cycles of metasepta have been inserted.

Symmetry.—Although septal insertion follows the most usual mode, the septal symmetry seen in ephebic stages of *Cymatelasma* is distinctive. It is blurred or slightly modified in some individuals, but is always based on the ideal plan shown in Text-fig. 14. The long cardinal and counter septa, whose axial ends are almost contiguous, lie in the plane of bilateral symmetry. The cardinal quadrants present no unusual feature; in them the metasepta increase progressively in length from the youngest, nearest the cardinal septum, to the oldest, which flank the alar septa. But in the counter quadrants, the youngest metasepta, near the alar fossulae, and the oldest, near the counter-lateral septa, are shorter than the intermediate metasepta. This arrangement is produced as follows: During ontogeny each metaseptum is short when inserted at the alar fossulae, and is deflected counter-wise as new metasepta are inserted; it increases in length until it reaches a position where it makes an angle of about 45 degrees with the counter septum; after this stage further deflection towards the counter septum is accompanied by relative decrease in length. The counter-lateral protosepta usually remain nearly as long as the counter septum.

---

[1] See D. Hill, Geol. Mag., LXXII, 1935, 502–506, and text-figs. 16–17.

[2] A. J. Butler, Geol. Mag., LXXII, 1935, 119.



Text-fig. 14.—Diagram showing ideal septal symmetry in *Cymatelasma*. C = cardinal septum; K = counter septum; A = alar septa; KL = counter-lateral septa; 1–6 = metasepta; M = minor septa; KLM = counter-lateral minor septa. As shown in the diagram there is usually one more metaseptum in each of the counter quadrants than in each of the cardinal quadrants.

The symmetry thus produced gives in transverse sections a false appearance of 6 points of septal insertion. It is identical with the septal symmetry in the genus *Spongophylloides* Meyer.[1]

EXPLANATION OF PLATE XVI.

All the figured specimens are in the Sedgwick Museum.

Fig.

1.—*Cymatelasma multiseptatum* sp. nov. Ephebic transverse section of holotype A 7760 *c*. Upper Llandovery, the Dingle, between Worcester Beacon and the Sugar Loaf, Malverns. × 2.

2–8.—*Cymatelasma corniculum* sp. nov.

2.—Longitudinal section of holotype A 7761 *e*. Woolhope Limestone, road cutting south of Stony Hill Farm, Woolhope. × 3.

3.—Transverse ephebic section of holotype A 7761 *f*. Locality and horizon as above. × 3.

4.—Transverse neanic section of holotype showing septal dilatation A 7761 *d*. Locality and horizon as above. × 3.

5.—Longitudinal section. Paratype A 7767 *c*. Woolhope Limestone, Rudge Farm Quarry, Woolhope. × 2.

6.—Transverse section near calice. Paratype A 7767 *d*. Locality and horizon as above. × 2.

---

[1] A. J. Butler, *Ann. Mag. Nat. Hist.*, **10**, xiii, 1934, 543–5, and text-fig.

FIG.

7.—Transverse ephebic section showing recrystallized septa. Paratype A 7763 *c*. Woolhope Limestone, 60–73 feet above *Petalocrinus* Bed, road cutting south of Stony Hill Farm, Woolhope. × 3.

8.—Transverse section, showing effect of cone-in-cone rejuvenescence. Paratype A 7762 *b*. Woolhope Limestone, 7–10 feet above *Petalocrinus* Bed, road cutting south of Stony Hill Farm, Woolhope. × 3.

9–13.—*Cymatelasma carinatum* sp. nov.

9.—Ephebic transverse section of holotype A 8360 *d*. Top of Nodular Beds, Wenlock Limestone, old quarry, opposite lime-kilns, south-west of Wren's Nest Hill, Dudley, Worcs. × 3.

10.—Transverse section of holotype, through bottom of calice, showing the septal symmetry A 8360 *f*. Locality and horizon as above. × 3.

11.—Longitudinal section, showing carinate septa and rejuvenescence. Paratype A 7776 *e*. Wenlock Limestone, Lower Quarry, Stretton Westwood, Wenlock Edge, Salop. × 2.

12.—Transverse ephebic section. Paratype A 8355 *e*. Basement Beds of Lower Wenlock Limestone, railway cutting near Daw End, Walsall, Staffordshire. × 3.

13.—Longitudinal section, showing highly carinate septa. Paratype A 8356 *f*. Locality and horizon as above. × 3.

14–17.—*Cymatelasma tardens* sp. nov.

14.—Transverse section of holotype, through bottom of calice A 7772 *d*. Lower Ludlow Shale. Ledbury Quarry Tip, Malverns. × 3.

15.—Longitudinal section of holotype, showing lumen filled by dilated septa. A 7772 *e*.

16.—Transverse ephebic section, showing dilatation and symmetry of the septa. A 7774 *b*. Locality and horizon as above. × 2.

17.—Longitudinal section showing deep calice and carinate septa. Paratype A 7775 *b*. Locality and horizon as above. × 2.

REVIEW.

BRITISH REGIONAL GEOLOGY. THE MIDLAND VALLEY OF SCOTLAND. By M. MACGREGOR and A. G. MACGREGOR. pp. vi + 89, with viii pls. and 16 text-figs. Department of Scientific and Industrial Research. Geological Survey and Museum, Edinburgh, 1936. Price 1*s*. 6*d*.

THE Midland Valley of Scotland, that broad lowland tract underlain by Carboniferous and Old Red Sandstone and diversified by many hill ranges of igneous rocks, stretches in a south-westerly direction from the east to the west coast, between the major dislocations which bound the Grampian Highlands to the north and the Southern Uplands to the south. It is thus an ancient rift-valley or graben bounded by tectonic lines of Caledonian direction. Nowhere in the British Isles is there a region more replete with features of stratigraphical and igneous interest. Dr. M. Macgregor and Mr. A. G. MacGregor have done full justice to its fascinating geology in this valuable addition to the handbooks illustrating British Regional Geology. While the work is naturally much condensed, considerable use having been made of tabular matter, the authors have managed to include a great deal of new and unpublished material gathered by Survey officers during the recent resurvey of the region, which is embodied in many newly drawn maps and sections. The general plan of the handbook is to deal with the formations—Ordovician to Permian—in order of age, giving first a general account of the formation, then of its palaeontology, and finally of the igneous rocks and their petrology. Two intercalated sections on the teschenitic, theralitic, and monchiquitic intrusions of Carboniferous and Permian ages, and on quartz-dolerite and tholeite dykes and sills of Permo-Carboniferous age respectively, are of special value in that they assemble all available data on these rocks in an orderly and easily assimilable form.

The cities of Edinburgh and Glasgow, with their great University geological schools, are situated in the Midland Valley, and possess perhaps the finest fields of study for students of geology of any University in the kingdom. Students, amateurs, and teachers of geology at these centres are to be congratulated on having this short but comprehensive handbook on the local geology at their disposal. The work is excellently written, finely illustrated, and splendid value at its low price.

G. W. T.

THE

GEOLOGICAL MAGAZINE

VOLUME LXXIII.

No. XII.—DECEMBER, 1936.

ORIGINAL ARTICLES.

The Idea of Contrasted Differentiation: a Reply.

By S. R. Nockolds.

I HAD not intended to reply to Professor Holmes's recent paper in the Geological Magazine,[1] but the apparent confusion of mind which exists about the question of contrasted differentiation has led me to do so.

The first portion of Holmes's communication deals with the Glen More ring dyke and argues against it being an example of gravitative differentiation. This is supposed to throw some doubt on the idea of contrasted differentiation, but it makes no difference to the idea at all. Personally, I have always believed that the transition rocks were hybrids and that the acid magma was introduced somewhat later than the basic component. There is no reason, however, why the acid rock should not be associated with the basic one, both being derived from the same source. It is this association which the idea of contrasted differentiation seeks to explain. The "marked pause in the process of crystallization" advocated by the authors of the *Mull Memoir* is probably quite rightly interpreted by Holmes as meaningless.

Now this *association* of acid and basic rock and their derivation from a common source, is fundamental for the hypothesis of contrasted differentiation. Holmes, however, denies that they are necessarily derived from a common source, i.e. that their formation is due to differentiation (Holmes, p. 235). We must therefore look into this question of association a little more closely. The type of magma which produces an interstitial acid residuum, acid segregation veins, etc., is that commonly known as the tholeiitic magma type.

---

[1] A. Holmes, Geol. Mag., LXXIII, 1936, 228–238. (In case any reader should be searching for the source of the quotation under the title of Holmes's paper, I ought perhaps to remark that it was taken by him from some unpublished notes on the eastern end of the Newry igneous complex which were sent to Miss Reynolds, after an excursion held there last August.)

This is characterized, as Kennedy[1] and others have shown, by the presence of pyroxene which is essentially hypersthene-augite (with or without rhombic pyroxene in addition). As Kennedy has shown again, this may be compared with the olivine-basalt magma type which carries olivine and a diopsidic pyroxene. The residual liquids of these two types, as shown by their segregation veins, etc., are quite different.[2] In the first case they are of acid granodioritic composition, in the second case they are of alkaline type. Why should there be this differing association of segregation veins unless both the vein and the basic rock are derived from a common source ? Furthermore, in the case of the Tertiary composite minor intrusions of Scotland, where an acid centre is present the basic component is a tholeiite or quartz-dolerite, and Kennedy[3] remarks, "Not a single case is known to the author in which typical olivine basalt magma enters into composite relationship with granophyre, rhyolite, or other quartzose acid rock." Why should this be so unless the tholeiite and the acid rock have a common origin ? Now differentiation is defined by Tyrrell[4] as "the process whereby a magma, originally homogeneous, splits up into contrasted parts, which may form separate bodies of rock, or may remain within the boundaries of a single unitary mass". If, therefore, the acid and basic portions in, say, a composite minor intrusion come from a common source, I see nothing wrong in saying that they have differentiated from that source.

Holmes's next criticism concerns the formation of the acid residuum. According to him, the acid residuum cannot form without the formation of intermediate liquids which would give intermediate types of rock (Holmes, pp. 228 and 236). What does he mean by "intermediate types of rock" ? If he means rocks of dioritic mineralogy with hornblende, etc., I disagree with him. If he means rocks of chemically intermediate composition, I agree. It is clear that as the tholeiitic magma crystallizes the liquid must pass through various intermediate stages before reaching that of the acid residuum. But how do these liquids behave ? The answer to this is given by the intermediate members of this magma type such as the leidleites. These do not crystallize with intermediate mineralogy but precipitate pyroxene, iron ore, and basic plagioclase, leaving a considerable residuum which, in the finely crystalline members, reveals itself as "an ill-defined crystallization of alkali felspar and quartz" (*Mull Memoir*, p. 281). Thus the intermediate members show the same contrasted association of minerals as do the quartz-dolerites themselves. Holmes, however, may mean that rocks with intermediate mineralogy between pyroxene and basic plagioclase on the one hand and the acid residuum on the other, should form. It is true that Bowen when discussing the gabbro-granophyre assemblage regards it as being due to high fractionation in the plagioclase reaction series, effected mainly by zoning. Further he says[1]: "The liquid passes through every gradation of composition between gabbro and granophyre, the product of crystallization at intermediate stages, say the dioritic, being represented by certain layers of the crystals and not by a separate rock mass. The discontinuity in the crystallization series, that is sometimes claimed, has no real existence." If this idea of high fractionation was true, however, the early formed material of, say, a quartz-dolerite would be armoured against attack by the acid residuum. In the rocks themselves there are often signs of attack, and Bowen himself remarks[2]: "Attack of the salic residuum upon surrounding minerals is no evidence of its secondary nature. The residuum formed by fractional crystallization should have a tendency to attack earlier minerals when these minerals are members of reaction series, and it is the failure of completion of this reaction that constitutes fractional crystallization." In view of the evidence of attack of the acid residuum on early formed crystals, I believe that the acid residuum is not in equilibrium with the early formed material and that, had reaction been completed, the residuum might not have appeared at all with its present composition. The acid plagioclase might have been used up in rendering the earlier plagioclase a little more acid (a little might have been utilized in the formation of hornblende from pyroxene), the orthoclase might have gone to the formation of biotite and only some free quartz might have been left. If we do not accept Bowen's explanation of zoning, how did the formation of the acid residuum come about?

---

[1] W. Q. Kennedy, *Amer. Journ. Sci.*, xxv, 1933, 241.
[2] W. Q. Kennedy, op. cit., 241–2.
[3] W. Q. Kennedy, op. cit., 249.
[4] G. W. Tyrrell, *The Principles of Petrology*, London, 1926, 148.

The authors of the *Mull Memoir*, as the result of a study of these rocks, reached the conclusion that the pyroxene and plagioclase (together with iron ore) separated out together and continued to do so until the residual liquid was almost depleted in these constituents (*Mull Memoir*, p. 330). Holmes, arriving at a similar conclusion, says[3]: "In a four-dimensional cooling diagram the liquid then appears to have closely approached or reached the groove of minimum temperature as between the three systems plagioclase, pyroxenes, and ores. While further consolidation takes place the liquid moves down the groove towards the lower temperature at which micropegmatite crystallizes. Since over this stage there is no important change of composition, the groove must dip very steeply towards the four-dimensional eutectic point at which micropegmatite appears, and by the time this point is reached most of the other constituents have crystallized out." If this is so, then after the pyroxene, iron ore, and plagioclase (averaging about $Ab_{50}An_{50}$) have crystallized out, it is clear (remembering the initial magma) that the residual liquid must have a highly contrasted character. Quartz has been stored up together with potash felspar and a plagioclase liquid whose composition would be about $Ab_{85}An_{15}$ if it was in equilibrium with solid plagioclase of about $Ab_{50}An_{50}$. If this liquid forms a glass or solidifies without being able to react further with the early crystals, it must possess a strongly contrasted composition. In the case of the quartz-dolerites, the failure of reaction must have been due to lack of time, and, indeed, in the coarser types we do see the beginnings of reaction with the acidification of the plagioclase, formation of hornblende and biotite, etc. At this stage of its career the magma has reached a turning point, the pyroxene now proceeding to react with the residual liquid to produce hornblende and biotite, and, judging by the amount of reaction to be observed in the coarser types of quartz-dolerite, such reaction is comparatively sluggish.

---

[1] N. L. Bowen, *The Evolution of the Igneous Rocks*, Princeton, 1928, 91.

[2] N. L. Bowen, op. cit., 73.

[3] A. Holmes and H. F. Harwood, *Min. Mag.*, xxi, 1926–8, 537.

With this lack of time for reaction we do not expect to obtain rocks which have, mineralogically, an intermediate composition. For instance, Tyrrell writes[1]: "With maintenance of contact between the early crystals and residual liquid, the contrast of composition is lessened, and the possibility of differentiation diminished; but if, by any means, a separation is effected between early crystals and residual liquid, the difference in composition is intensified owing to the lack of mutual reaction, and separate bodies of rock are produced which are strongly contrasted in composition." Bowen[2] says much the same thing. There seems to be nothing in this which is at variance with work on silicate melts. Even if it was at variance with such work, Holmes's attitude seems strangely inconsistent. On a later page he discusses Fenner's evidence (which is no doubt correct) of the solution of large amounts of basalt in a rhyolite magma (Holmes, p. 237). This is also at variance with such work as has yet been done on silicate systems, according to which silica always appears in the lowest melting eutectic and a rhyolitic liquid should be comparatively cool. But Holmes does not dismiss Fenner's evidence on this account. Instead there is a short discourse on unknown sources of energy, limits to our understanding, etc.

Of course, any method which will hinder reaction between the early formed crystals and residual liquid may be brought into play. In magma reservoirs there might be plenty of time for reaction, but here it might be prevented by the sinking of the early crystals or by the bodily removal of the acid residuum. Here we have to meet another criticism of Holmes who says that the residual liquid could neither be separated by gravitational filtration (Holmes, p. 230) nor squeezed out without causing intense deformation of the crystal mesh (Holmes, p. 231). This view is partly based on the fact that the acid residuum of the Whin Sill is no more than 5·5 per cent. This, however, does not mean that it is the maximum amount of residuum which could be obtained. For instance, if one takes the average Scotch quartz-dolerite (Palaeozoic) and the average of the two acid segregation veins given by Walker,[1] it is possible to construct the normal diagram for this purpose (ignoring the minor constituents and water) and see what has to be subtracted from the quartz-dolerite to give the acid vein. There are, of course, an infinite number of solutions. If the most basic material which could be subtracted was taken, then about 32 per cent of acid material could be formed. The normative plagioclase of this is $Ab_{28}An_{72}$, but as that of the veins is about $Ab_{86}An_{14}$ this would imply some curious discontinuity of crystallization. If we are contented with about 15 per cent of acid residuum, the material to be subtracted has the following approximate composition :—

---

[1] G. W. Tyrrell, op. cit., 155.
[2] N. L. Bowen, op. cit., 56.

				Norm.	
SiO_2	48·0		qu	3·5	
Al_2O_3	14·2		or	2·8	
Fe_2O_3	6·1		ab	19·4	46·4 ($Ab_{42}An_{58}$)
FeO	9·6		an	27·0	
MgO	6·3	di	Ca	9·3	
CaO	9·9		Mg	5·8	
Na_2O	2·3		Fe	2·9	
K_2O	0·5	hy	Mg	9·9	
TiO_2	2·9		Fe	4·9	
			il	5·5	
	99·8		mg	8·8	

Allowing for the fact that both in this and in the segregation vein the normative plagioclase will be a little richer in anorthite than the modal plagioclase, especially in the subtracted material, there is quite good agreement between the composition of the plagioclase in the subtracted material and that of the segregation veins on the assumption that the latter represents the composition of the plagioclase liquid at the time. If the same process is adopted for the average Whin Sill magma [2] and an acid segregation vein [3] and material subtracted with the same silica percentage as before, there would be about 20 per cent of acid residuum, but as the normative plagioclase in this is fairly basic, the result is probably a little too high.

It seems quite possible, however, that the acid residuum could amount to at least 15 per cent under favourable circumstances. This would probably be more than sufficient for a separation to occur in a magma reservoir. If the final residuum of augite-andesites can ooze into vesicles when it only forms a very small proportion of the mass, there seems to be no reason why the acid residuum we are considering cannot also move quite readily, particularly when it is remembered that the volatiles of the magma have also been concentrated in this residuum which will thus be highly mobile. Why should the separation of crystals and residuum take place nearly always at this stage? It does not always do so because intermediate types like the leidleites are known, but in general the plagioclase and pyroxene have nearly finished their crystallization before the acid residuum is removed. This is perhaps due to the pyroxene and plagioclase crystallizing out through a comparatively small temperature range so that they have finished crystallizing at a relatively early stage in the cooling history of the magma. Then unless the residual liquid was removed during this comparatively short space of time, intermediate types would not form.

---

[1] F. Walker, *Min. Mag.*, xxiv, 1935, 152.

[2] A. Holmes and H. F. Harwood, op. cit., 537.

[3] S. I. Tomkeieff, *Min. Mag.*, xxii, 1929–1931, 110.

What alternative suggestions does Holmes put forward to account for the association of acid and basic rocks and the formation of an acid residuum in the quartz-dolerites? As far as I can make out these are (*a*) assimilation, and (*b*) some process of gaseous distillation. With regard to (*a*) there is no objection to assimilation of appropriate material augmenting the amount of acid residuum, but the process by itself does not account for the world-wide distribution (in continental regions) of a more or less uniform tholeiitic magma with its own peculiar mineralogy. Nor does it account for the fact that these rocks crystallize with the separation of pyroxene and basic plagioclase even in the types of intermediate chemical composition, leaving a residuum of highly contrasted nature. Why should the acid material remain as such if assimilation has been the only process at work?

It is impossible to discuss gaseous distillation because no details are given of the process. We are not told how it acts, what it is, or even from whence the emanations came. In this respect the hypothesis bears a close resemblance to that of Clifton Ward (put forward in 1876), when he says[1]: "But metamorphic action is varied; and although a simple melting down of clay slate might never produce granite, yet a moist fusion, accompanied by elementary substances, brought upwards from still greater depths, might effect a great transformation."

As mentioned in my original paper, there is also evidence of contrasted differentiation amongst the olivine-basalts with their sharply contrasted alkaline segregation veins. Holmes entirely ignores these. Are these also to be ascribed to assimilation or gaseous distillation?

Summing up, I still believe—

(*a*) That sharply contrasted acid veins or intrusions are often associated with rocks of tholeiitic magma type and sharply contrasted alkaline ones with rocks of olivine-basalt magma type.

(*b*) There is evidence in both cases that the associated veins or intrusions and the basic rocks have a common origin.

---

[1] J. C. Ward, *Quart. Journ. Geol. Soc.*, xxxii, 1876, 30.

(*c*) That in the tholeiitic magma type the pyroxene and plagioclase (together with iron ore) crystallize early, reacting with the liquid in the normal way until they have almost exhausted it in these constituents. At this stage a residuum is left of highly contrasted composition. If this cannot react with the early formed crystals (through lack of time in the case of the quartz-dolerites or through separation of crystals and liquid in a magma reservoir) it will solidify as an acid residuum or separate intrusion.

(*d*) That the tendency to behave like this is inherent in the magma type and extends even to the intermediate types which still show the early separation of pyroxene and plagioclase with an increased amount of acid residuum.

(*e*) That the process does not appear to be at variance with work on silicate melts but that, if it should turn out to be so, " these difficulties limit only our understanding ; they can no longer be regarded as setting a natural limit to the properties of magmas " (Holmes, pp. 237–8).

(*f*) This is not necessarily the only way in which acid magma can form.

Finally, Holmes remarks (p. 238) : " So far the only differentiation process which holds out any approach towards a solution is one involving gaseous distillation from an unknown ultimate source in the hidden depths." I cannot help feeling, with all due diffidence, that the idea of contrasted differentiation for which there is no evidence (Holmes, p. 236) and which cannot be claimed as a hypothesis at all (Holmes, p. 238), may yet prove more serviceable than a process of gaseous distillation in which rocks are acted upon by unspecified emanations (in an unspecified manner) coming from an unknown source at unknown depths.

Age of the Girvan-Ballantrae Serpentine.

By J. G. C. Anderson, Carnegie Research Fellow, University of Glasgow.

I. Introduction and Historical.

BETWEEN Kennedy's Pass, 4 miles south of Girvan, and Currarie Port, 3½ miles south of Ballantrae, the coast is occupied by a varied assemblage of igneous rocks that have a north-easterly strike and extend inland for several miles (Text-fig. 1). The most important members of this assemblage are a series of spilite lavas and two large outcrops of serpentine. In the present paper it is not intended to give a general description of these rocks, but to concentrate upon the age-relationship of the serpentine to the lavas and associated sediments, in which Lapworth and later workers discovered Arenig fossils.

The earliest remarks about the serpentine appear to have been made in 1844 by Nicol (p. 31) and in 1851 by Murchison (p. 153).

The latter was the first of a long line of geologists to compare it with that of the Lizard. In 1858 Greg and Lettsom (p. 219) also mentioned the rock. In 1866 James Geikie gave a detailed account of the igneous rocks of the district, but regarded the serpentine, along with most of the other types, as of metamorphic origin. Murchison refused to accept this view in its entirety in the 1867 edition of *Siluria* (p. 155), and D. Forbes had a somewhat bitter controversy with Geikie on the subject in the GEOLOGICAL MAGAZINE of the same year.

In 1878 Bonney, drawing upon his experience in the Lizard, showed that the serpentine was an altered olivine-rock of igneous origin. The same author also recognized the presence of lavas and agglomerates. These volcanic rocks were believed to be of Old Red Sandstone age, and the serpentine a later intrusive. Lapworth's chief contribution to the igneous geology of the Girvan-Ballantrae area appeared in 1889. The volcanic rocks were shown to be of Arenig age, but it was suggested that the intrusion of the serpentine took place after the deposition of the Girvan rocks and possibly in post-Silurian times.

In 1899 appeared the great memoir on the Silurian rocks of Scotland, written by Peach and Horne, and supplemented by petrographic notes by Teall. There it is claimed that the Arenig lavas with their associated black shales and radiolarian cherts were invaded by serpentine and subordinate gabbro, dolerite, and granite before the close of Arenig times. The local occurrence of schistose varieties is duly recorded.

In 1932 Balsillie published a general account of the igneous rocks of the region. No attempt is made to interpret the age-relationship, but it is indicated that in the author's opinion this needs revision. The same year the Geologists' Association visited Girvan, and Pringle (1933, p. 57) put forward the view that the intrusive rocks form a pre-Arenig, probably pre-Cambrian, basement. In 1935 Balsillie further advocated this idea in a note on the occurrence of fragments of intrusive types, some of them metamorphosed, in Arenig agglomerates. Finally Pringle has maintained this interpretation in a Regional Memoir on the South of Scotland (1935, pp. 5 and 14) and Balsillie in a letter to the *Scotsman* (1936).

Practically the whole outcrop of the Girvan-Ballantrae igneous complex is shown on 1 in. Sheet 7 of the Geological Survey (Scotland).

II. EVIDENCE OF THE AGE OF THE SERPENTINE.

A very detailed study was made of the junction of the serpentine with Arenig rocks. In many cases the contacts examined were of an unsatisfactory character, but it has been considered advisable to put observations made at such localities briefly on record along with evidence of a more positive nature. The most important evidence is supplied by the Pinbain shore section and the schistose contacts between Carleton Hill and Loch Lochton.

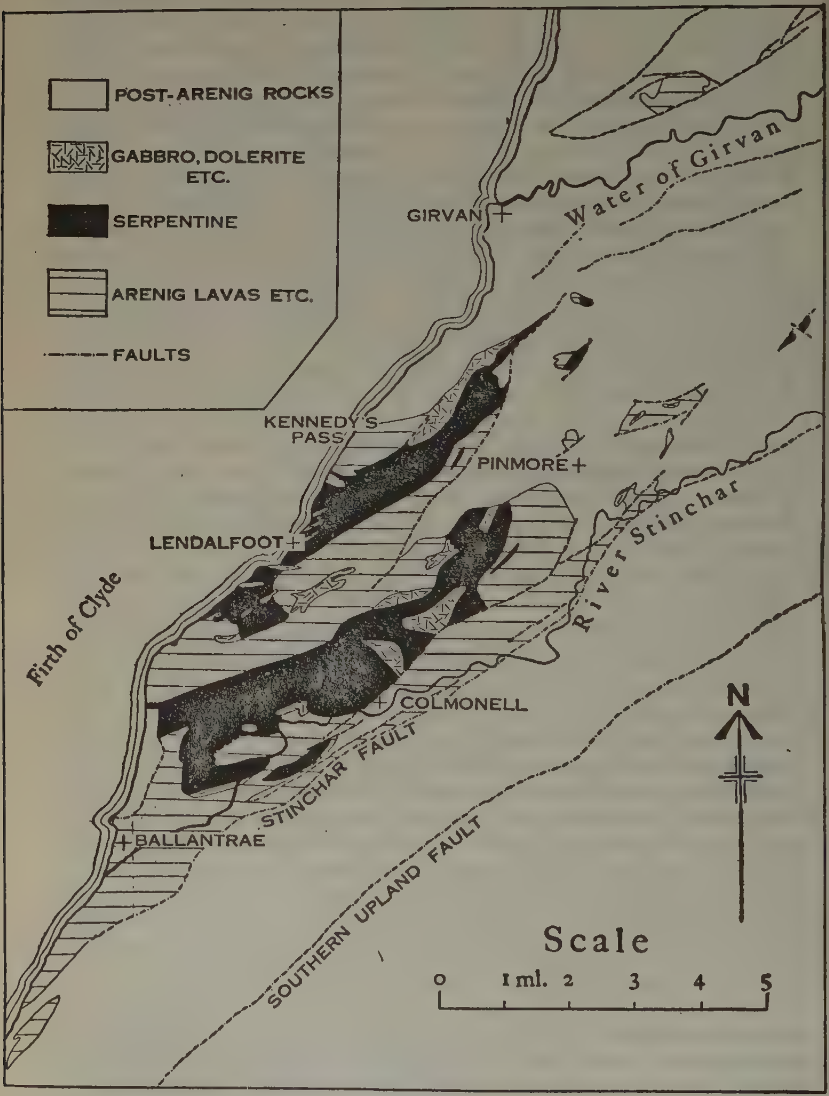
Contacts without Schistose Developments.

Pinbain Shore Section (Text-fig. 2).—A large-scale plan and a lengthy description of this section is given by Peach and Horne (1899, Fig. 104, and pp. 442–4). New and highly important evidence has been discovered at the northern end of the exposure, about 170 yards north of the Pinbain burn. Here a good landmark is afforded by a band of green porphyritic spilite rising above the general level of the beach. It may be mentioned that this spilite, at least as far as the present shore section is concerned, instead of being faulted against ashy shales to the north, as shown on Peach and Horne's figure, is transgressively intrusive. In the case of submarine igneous activity, however, the distinction between a true subaqueous flow and an intrusion into a thin cover of wet sediments is slight, and of little significance in the general story (Harker, 1909, p. 64). By some authors even pillow-lavas in certain cases are considered to be intrusive into soft mud (Lewis, 1914, p. 652, and Benson, 1915, p. 123).

South of the porphyritic spilite Peach and Horne have mapped a belt of serpentine exposures. These can be locally separated into two rather narrow bands, and the country-rock, at any rate in places, is dark green fine-grained shaly tuff, well-banded and with suggestions of graded bedding. The best exposures of this tuff are near a little Tertiary dyke. South of the more southerly band of serpentine rises a small knoll of non-porphyritic spilite with doubtful pillow-structure. This knoll measures 12 feet by 5 feet by 4 feet high, and is situated 115 feet 20° south of west of a point where the seaward verge of the road is cut by a small drainage ditch and where a break occurs in the retaining wall at a rock-pinnacle. On the south side of the knoll *serpentine is seen in contact with the lavaform rock*, and it has been found possible to collect actual junction specimens. On slicing[1] these leave no doubt of the intrusive nature of the ultrabasic rock, which fingers into the lavaform rock and frequently cuts across felspar laths (Text-fig. 3). The injected material is for the most part serpentine of undoubted igneous origin, though here and there are later veins of much finer serpentine which may be either igneous or hydrous. The lavaform rock is somewhat serpentinized, and in the field this has the effect of giving it a purple colour which a few inches from the contact rapidly fades into the normal greenish-grey of the spilite. Contact metamorphism of the normal sort is absent at Pinbain. The present author's work has confirmed that this is universally the case in the Girvan-Ballantrae district as far as the rocks surrounding the serpentine are concerned. It is probably due to intrusion taking place into lavas and sediments thoroughly soaked in sea-water. It may be added that du Rietz finds no contact alteration produced in invaded rocks by the Lower Ordovician serpentines of Northern Sweden (1935, p. 138).

---

[1] Slices Nos. 6271–3 in the collection of the Geology Dept., University of Glasgow.



Text-fig. 1.—Arenig Rocks of the Girvan-Ballantrae Area.

Apart from the unequivocal evidence described above, the general impression left by the section at the north end of the Pinbain shore is that of tongues of serpentine intruded into an assemblage of lavaform rocks and tuff. There is nothing to suggest that the serpentines are separated from their associates by an unconformity. This holds also at all other points where the margin of the serpentine can be closely examined.

South of the mouth of Pinbain burn serpentine is seen practically in contact with black shale which has yielded *Amplexograptus* [*Climacograptus*] *confertus* (Peach and Horne, 1899, p. 442). Unfortunately a thin Tertiary dyke intervenes. The serpentine on the south side of the dyke becomes finer as the shale is approached, thus suggesting a chilled margin, but when dealing with serpentinized rocks it is perhaps unwise to base much on such evidence.

Games Loup (*2 miles south-west of Lendalfoot*) (Text-fig. 1).—Here unmoved serpentine has been traced near low-water mark to within 6 inches of a cliff of green spilite lava.

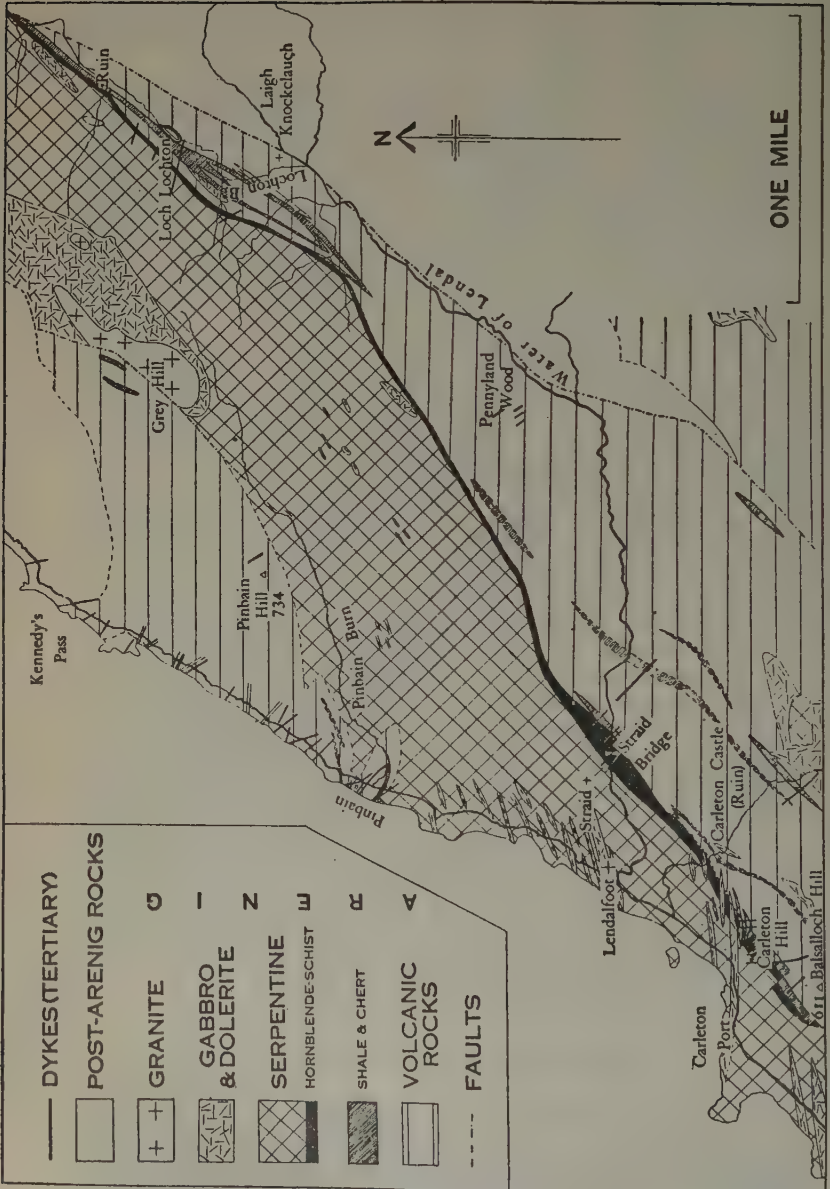
Bennane Head (*2 miles north of Ballantrae*) (Text-fig. 1).—A plan of the shore at Bennane Head is given by Peach and Horne (1899, fig. 102), and from this it will be seen that the contact of serpentine and Arenig strata is obscured partly by an intrusion of gabbro and partly by present beach deposits. At the eastern side of the mouth of a large quarry just north of the Bennane Burn, however, a contact has been exposed by digging between serpentine and bedded ash. The rock is very dirty and decomposed, but at the actual junction there are a few inches of basaltic material followed by a very decomposed fine-grained type which might be chilled ultrabasic rock.

River Stinchar.—At the base of Knockdolian Hill (3 miles north-east of Ballantrae) (Text-fig. 1), when the river is low serpentine may be seen very close to a lavaform type which is best described as augite-andesite. The serpentine gives the impression of being a genuine chilled ultrabasic with porphyritic pseudomorphs in an original fine ground. Associated with the lavaform rock is a considerable outcrop of chert, but the contact of serpentine and black shale described by Peach and Horne (1899, p. 471) was not observed.

Breaker Hill (*2 miles south-west of Pinmore*) (Text-fig. 1).—In a small burn on the north-east face of Breaker Hill a contact is exposed between a small lenticular mass of serpentine and lava. Six feet away from the latter occurs very good serpentine. Between that point and the lava the rock is decomposed and difficult to determine, but a slide of the actual contact reveals a very fine serpentine, almost certainly a chilled rock, against the lava.

Contacts with Schistose Developments.

Carleton Hill to Loch Lochton.—As pointed out by Peach and Horne (1899, pp. 456–9), the margin of the serpentine, intermittently exposed from Carleton Hill to Loch Lochton, a distance of 4 miles, coincides with a line of movement, along which a variety of highly sheared rocks have been developed (Text-fig. 2).


DYKES (TERTIARY)
POST-ARENIG ROCKS
GRANITE
GABBRO & DOLERITE
SERPENTINE
HORNBLENDE-SCHIST
SHALE & CHERT
VOLCANIC ROCKS
FAULTS
ARENIG
N
ONE MILE
Ruin
Laigh Knockclauch
Loch Lochton
Lochton Burn
Grey Hill
Water of Lendal
Pennyland Wood
Kennedy's Pass
Pinbain Hill 734
Pinbain Burn
Pinbain
Straid
Straid Bridge
Carleton Castle (Ruin)
Lendalfoot
Carleton Hill
611 Balsalloch Hill
Carleton Port

On the steep seaward slope of Carleton Hill frequent exposures of purple and green rocks, with a strong flaser structure striking north-east and dipping at a high angle to the north-west, intervene between the serpentine and an assemblage of tuff, shale, and lava. The schistose belt is at least 100 feet wide in places, and is traversed by unsheared dolerite dykes that belong to the post-serpentine part of the Arenig suite. Flaser rocks also outcrop in a stream north of Carleton Castle, and in the Water of Lendal. An excellent exposure is seen just south of the latter stream, a short distance west of Straid Bridge. Here there occurs an outcrop 23 feet wide of fine-grained, strongly banded hornblendic schist, with vertical foliation planes striking 25 degrees east of north.

For the next 2 miles there are no exposures of this marginal shear-belt but, on the other hand, there is no evidence that it does not exist. The schistose rocks reappear in a small quarry in the hill-side 550 yards west by south of Laigh Knockclauch, and from there to beyond Loch Lochton outcrop with fair frequency. A detailed description of this area would in the main simply be a repetition of that given by Peach and Horne (1899, pp. 458–9). Certain alterations in details of mapping and interpretation may, however, be mentioned. Thus " the lenticular strip of garnetiferous hornblende-schist—near the margin of the serpentine but apparently surrounded by that rock ", a quarter of a mile south-west of Loch Lochton, is taken on Text-fig. 2 as purely marginal. Then, west of a fault bringing down post-Arenig rocks to the east, for some distance north of Laigh Knockclauch, instead of serpentine, as on Sheet 7, lavas and associated rocks are shown on Text-fig. 2. Finally in a stream, which flows eastward past a ruined cottage a quarter of a mile north of Loch Lochton, Peach and Horne mention " shattered and altered lavas " (shown on Text-fig. 2 under same ornament as hornblende-schist) between black shale and hornblende-schist. Slides of the material in contact with the shale, however, reveal a rock, which, though it has a fine-grained variolitic groundmass similar to that of some of the lavas, at the same time shows well-shaped quartz-chlorite-calcite pseudomorphs after olivine phenocrysts and abundant irregular grains of picotite. It seems extremely likely that we are here dealing with an original chilled edge of the ultrabasic complex, now separated from the main serpentine mass by the shear belt, which at this point is 45 feet broad.

The commonest mineral of the schistose rocks is a greenish-brown hornblende, drawn out in the direction of foliation. Epidote is also fairly abundant along certain planes. Sericitized felspar is present and a little quartz, but biotite has not been observed. The texture varies considerably: on the whole the rocks are fine-grained and sometimes strikingly so. Garnets occur sporadically and range up to a little over 1 mm. in diameter. They are generally marginally altered to fibrous amphibole. It is impossible to be certain whether these garnets are of igneous or of metamorphic origin, but as none has been observed in the unsheared rocks of the area it is probable the second alternative is correct.

The original nature of these schistose rocks cannot be determined with certainty. Possibly the coarser varieties represent basic marginal facies of the ultrabasic intrusion and the finer varieties volcanic rocks lying outside the latter. In particular examples from above Straid Bridge suggest derivation from tuffaceous sediments. Whatever their origin, it is clear that such schistose types must have been produced under conditions not of dynamic metamorphism alone but of dynamic metamorphism acting at a high temperature, and therefore they provide strong support for the intrusive theory.

Similar rocks, some of them stated to represent " effusive spilites " and others " intrusive diabases and gabbros ", occur in the Ordovician serpentine zone of the Highland Border (Jehu and Campbell, 1917, p. 199). Other analogies are provided by foliated types found as part of a screen lying within the south-eastern part of the Devonian Etive Granite Complex of the Dalmally district (Kynaston, 1908, pp. 96–102). Unpublished work by the present author has shown that quartz-plagioclase-biotite-schists have here been developed from Lower Old Red andesite lavas during the introduction of neighbouring plutonic intrusions. Foliated types have also been described by Brögger (1890, pp. 115–18) as produced from lavas (lately shown to be Permian) in the south of Norway during the intrusion of a laurvikite mass. From Swedish localities Törnebohm has described pre-Cambrian garnet-bearing diorite-schists and schistose amphibolites along the border zones of hyperite masses (quoted from Brögger, 1935, p. 96). The garnets are interpreted as replacing olivine.

The persistence of a *narrow belt* of schistose rocks along one of the main contacts of the Girvan-Ballantrae serpentine seems to dispose of the unconformity theory. It can readily be interpreted in terms of marginal shearing, if the contact is an original intrusive junction, but it has no meaning if the contact is an erosion surface. It must be remembered that the schistose rocks are of a type demanding high temperature at the time of their production and that they are cut by non-schistose dykes of the Arenig suite.

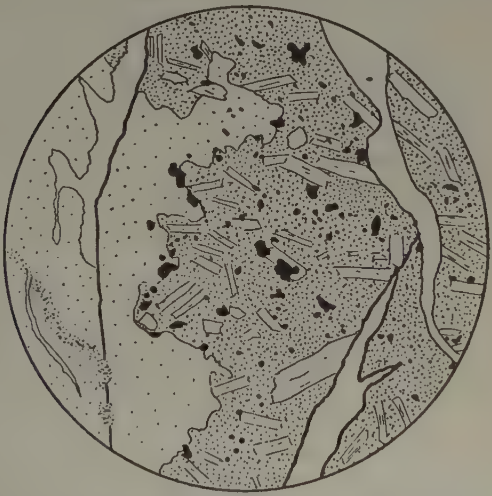
Balsillie's observation that fragments of ultrabasic and basic rocks, some sheared and altered, occur in Arenig agglomerates does not in itself suggest a pre-Arenig date for these intrusions. For instance, the Tertiary ashes of the Hebrides abound in fragments of Tertiary plutonics.

III. Comparison with Other Areas.

The Girvan-Ballantrae assemblage reappears along the Highland Border, on the north side of the Midland Valley synclinal. Here spilite lavas with cherts and black shales which have yielded Cambro-Ordovician fossils are associated with gabbros and serpentines (Jehu and Campbell, 1917). In Ireland the outcrop of the Highland

Border rocks greatly widens and the Tyrone Igneous Series (Hartley, 1933) with pillow-lavas, tuffs, black shales, and cherts invaded by gabbro (which shows local foliation), dolerite, and granite provides an analogy with the Girvan rocks, although a recent fossil discovery suggests that part may be of slightly later date (Hartley, 1936).

A very close parallel to the Girvan-Ballantrae igneous assemblage is found in the ophiolites of the Alps (Staub, 1922) and Apennines (Steinmann, 1926). Ophiolite is a general term including serpentine, gabbro, and spilite, and authors are agreed that all three are intimately associated in time as well as in space, and, in fact, are of comagmatic origin. The formation of the ophiolites is believed to have taken place in Cretaceous times, and as they are commonly associated with deep-sea deposits it is considered they were formed under abyssal conditions in the early Alpine geosyncline.



TEXT-FIG. 3.—Serpentine, undoubtedly derived from ultrabasic igneous rock and shown by open dotting, cuts spilite with recognizable felspars, often pseudomorphed, and magnetite. Both are cut by finer-grained serpentine, left clear in drawing. × 20.

For a further analogue we may turn to the great serpentine belt of New South Wales (Benson, 1913). Here a highly disturbed and altered series to the east is separated by a thrust from a less folded and less altered series to the west. In both series there is a large proportion of chert, spilite, and tuff; all the rocks are of Devonian to Carboniferous age. Along the thrust for 200 miles there occurs a great sheet of serpentine, which Benson considers to have been intruded in late Carboniferous (Hercynian) times during the actual formation of the thrust. Associated with the ultrabasic rock are gabbro and dolerite.

IV. CONCLUSIONS.

Although its significance has been disputed, the presence of radiolarian cherts renders it likely that in Arenig times very deep-water conditions prevailed in the Girvan-Ballantrae district. In such circumstances tapping of the basic substratum of the crust, or Sima, would be greatly facilitated. Magma arising from this layer, possibly along an incipient thrust (abyssal injection of Daly, 1933, pp. 260–3), was probably gravitationally differentiated into basic and ultrabasic portions. The basic material would be much more suited to contend with the unfavourable conditions produced by the great overlying mass of cold sea-water and would therefore be extruded first (or in some cases intruded into a thin cover of wet sediments) to form the spilitic lavaform rocks.

Once this was accomplished the ultrabasic magma would be intruded under the roof thus formed. Serpentinization probably took place simultaneously with solidification, the water of serpentinization being provided by the ocean. A further injection of basic material would then produce the gabbros and dolerites with the Byne Hill and Grey Hill granite as a local differentiate. During all this time tectonic movements would produce shear-belts and local foliation. Saussuritization of the basic rocks, like albitization of the spilites and serpentinization of the ultrabasic material, was probably a result of subaqueous conditions.

The demonstration of an Arenig age for the serpentine thus makes it possible to envisage a sequence of events in the Girvan-Ballantrae area during a deep-water phase of the Caledonian geosyncline closely analogous to that which took place under similar conditions in the younger Hercynian and Alpine geosynclines in other parts of the world.

V. ACKNOWLEDGMENTS.

The author's thanks are due to Professor E. B. Bailey and to Dr. G. W. Tyrrell for invaluable encouragement and advice throughout the preparation of this paper, to Dr. A. Lamont for assistance in the collection of specimens, and to H.M. Geological Survey for affording every facility to examine relevant 6 in. maps. Part of the cost of illustration was covered by a generous grant from the Carnegie Trust for the Universities of Scotland.

VI. LIST OF REFERENCES.

BALSILLIE, D. 1932. "The Ballantrae Igneous Complex, South Ayrshire," GEOL. MAG., LXIX, 107–131.

—— 1935. *Age Relations of the Ballantrae Igneous Complex, South Ayrshire,* privately published, St. Andrews.

—— 1936. "Lewisian Rocks in South Scotland," *Scotsman*, 11th April.

BENSON, W. N. 1913. "Spilite Lavas and Radiolarian Rocks in New South Wales," GEOL. MAG., L, 17–21.

—— 1913. "The Geology and Petrology of the Great Serpentine Belt of New South Wales," pt. i, *Proc. Linn. Soc., N.S.W.*, xxxviii, 490–517.

—— 1915. "The Geology and Petrology of the Great Serpentine Belt of New South Wales. Pt. IV: The Dolerites, Spilites, and Keratophyres of the Nundle District," *ibid.*, xl, 121–173.

Bonney, T. G. 1878. "On the Serpentine and Associated Igneous Rocks of the Ayrshire Coast," *Quart. Journ. Geol. Soc.*, xxxiv, 769–785.

Brögger, W. C. 1890. "Die Mineralien der Syenitpegmatitgänge der südnorwegischen Augit- und Nephelinsyenite," *Zeit. f. Kryst. und Min.*, xvi.

—— 1934. "The South Norwegian Hyperites and their Metamorphism," *Skrifter Videnskaps-Akademi i Oslo*, I. Matem.-Naturvid. Klasse. No. 1, 1–421.

Daly, R. A. 1933. *Igneous Rocks and the Depths of the Earth*, New York.

Forbes, D. 1867. "On the Alleged Hydrothermal Origin of Certain Granites and Metamorphic Rocks," **Geol. Mag.**, IV, 49–59 and 225–230.

Greg, R. P., and **Lettsom**, W. G. 1858. *Manual of the Mineralogy of Great Britain and Ireland*, London.

Geikie, J. 1866. "On the Metamorphic Lower Silurian Rocks of Carrick, Ayrshire," *Quart. Journ. Geol. Soc.*, xxii, 513–534.

—— 1867. "On the Alleged Hydrothermal Origin of Certain Granites and Metamorphic Rocks," **Geol. Mag.**, IV, 176–182 and 287–8.

Harker, A. 1909. *The Natural History of Igneous Rocks*, London.

Hartley, J. J. 1933. "The Geology of North-Eastern Tyrone and the adjacent portions of County Londonderry," *Proc. Roy. Irish Acad.*, xli, B 16, 218–285.

—— 1936. "The Age of the Igneous Series of Slieve Gallion, Northern Ireland," **Geol. Mag.**, LXXIII, 226–8.

Jehu, T. J., and **Campbell**, R. 1917. "The Highland Border Rocks of the Aberfoyle District," *Trans. Roy. Soc. Edinb.*, lii, 175–212.

Kynaston, H. 1908. In "The Geology of the Country near Oban and Dalmally," *Mem. Geol. Survey.*

Lapworth, C. 1889. "On the Ballantrae Rocks of the South of Scotland and their Place in the Upland Sequence," **Geol. Mag.**, XXVI, 20–24 and 59–69.

Lewis, J. V. 1914. "Origin of Pillow Lavas," *Bull. Geol. Soc. Amer.*, xxv, 591–654.

Murchison, Sir R. I. 1851. "On the Silurian Rocks of the South of Scotland," *Quart. Journ. Geol. Soc.*, vii, 137–178.

—— 1867. *Siluria*, 4th ed., London.

Nicol, J. 1844. *Guide to Geology of Scotland*, Edinburgh.

Peach, B. N., and **Horne**, J. 1899. "The Silurian Rocks of Scotland, Vol. I, Scotland," *Mem. Geol. Survey.*

Pringle, J. 1933. In "Report of Summer Field Meeting, 1932: Girvan-Ballantrae," *Proc. Geol. Assoc.*, xliv, 57–9.

—— 1935. "British Regional Geology: The South of Scotland," *Mem. Geol. Surv.*

Rietz, **Torsten du**. 1935. "Peridotites, Serpentines, and Soapstones of Northern Sweden," *Geol. För. Förh.*, Stockholm, lvii, 133–260.

Staub, R. 1922. "Ueber die Verteilung der Serpentine in den alpinen Ophiolithen," *Schweiz. Min. u. Petr. Mitt.*, ii, 78–149.

Steinmann, G. 1926. "Die ophiolitischen Zonen in der mediterränen Kettengebirgen," *Congr. Géol. Internat.*, xiv session, Madrid, Fasc. 2, 637–667.

Teall, J. J. H. 1899. In "The Silurian Rocks of Britain, Vol. I, Scotland," *Mem. Geol. Survey.*

Reinterpretation of the Bray Series at Howth, Irish Free State.

By Archie Lamont, Formerly Carnegie Research Fellow,
University of Glasgow.

(PLATE XVII.)

AMONG other parallels to the structures which he regarded as "crush-conglomerates" in the Manx slates, G. W. Lamplugh (1895, 586–7) mentions beds with isolated fragments in the Bray Series, at Howth, Co. Dublin. The age of this Series of slates and quartzites is rather conjectural. Fossil evidence, founded on such forms as *Oldhamia*, though supplemented by W. J. Ryan and T. Hallissy, who suggest Middle Cambrian (1912, 249), is inconclusive. More recently, E. Greenly proposes a pre-Cambrian age (1919, 896). The alternating (or greywacke) type of sedimentation seen in the beds recurs many times during Dalradian, Cambrian, Ordovician, and Silurian. Two schools in the interpretation of the Series have to be considered. The older school, with J. Kelly (1853, 240, 253–262) and G. H. Kinahan (1878, 12, 14) as its adherents, ascribed the fragmentation in the shaly beds to volcanic agencies, and, since they failed to distinguish cleavage from bedding, regarded many of the quartzites as intrusive. The younger school, including A. McHenry and W. W. Watts (1898, 17) and Lamplugh (1903, 6), described the breccias as produced by friction during regional earth-movements. The latter, as W. J. Sollas puts it (1893, 98), possibly extended from post-Ordovician to post-Carboniferous. While the effect of later crushing and faulting must not be overlooked, it seems necessary in the light of recent work by E. B. Bailey (1930, 86–90), Bailey and J. Weir (1932, 429–458), and S. M. K. Henderson (1935, 487–509), to invoke probable seismicity and contemporaneous slumping to explain the alternating beds and associated shaly breccia. A new suggestion will be advanced regarding the quartzites.

Three main coastal sections may be taken as typical: (1) South side of Balscaddan Bay, from Howth eastward to the Stag and Puck's Rocks, (2) Gaskin's Leap and Freshwater Bay, (3) Hippy Hole, Needles, and Drumleck Point.

(1) In the cliff just south of the Stag shaly breccia is well displayed. It contains small disorientated fragments of shaly and quartzitic rock and one large 5 ft. boulder of quartzite (Pl. XVII, Fig. 1). It is penetrated in an irregular fashion by quartzite. In the Stag itself the quartzite is brecciated into small angular pieces. This may have originated in a fault-chasm. Similar quartzite-breccia is found near low-water mark along most of the shore of Balscaddan Bay. Towards Howth it cuts across the seaward extension of vertical layers of shale and quartzite which retain some traces of the original bedding. The quartzites here are often bent in arcuate fashion and

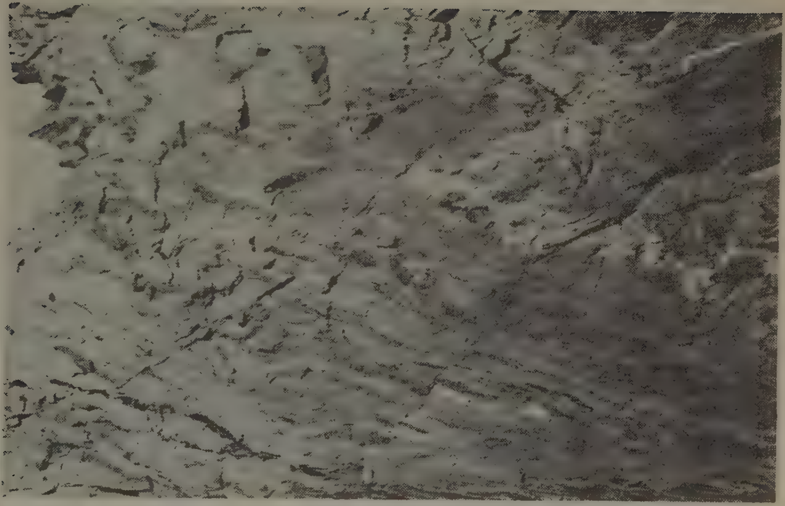


FIG. 2.

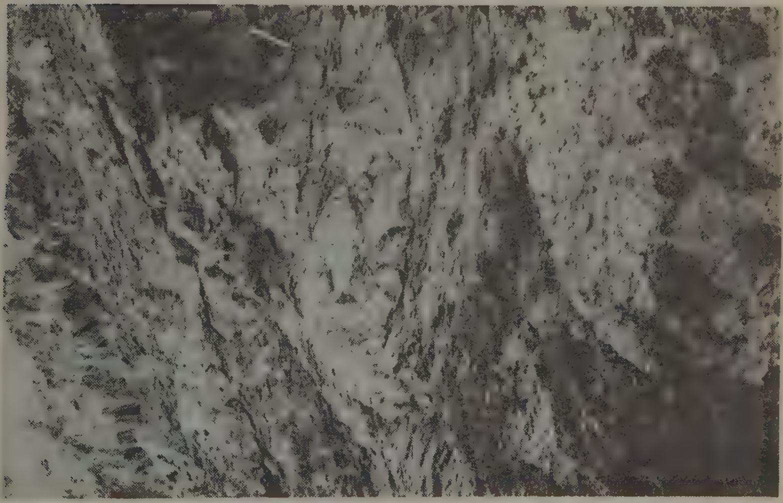


FIG. 1.

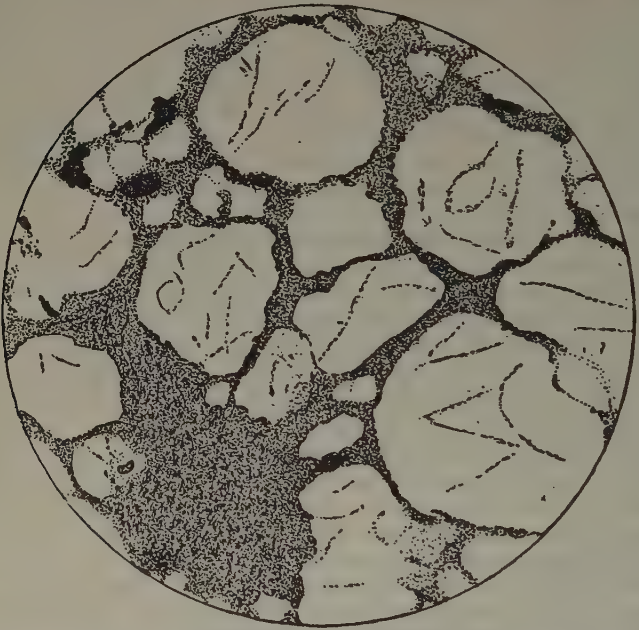
affected by horizontal faults. At Puck's Rocks normal interstratification of shaly and quartzitic beds may be examined. The strata do not appear much disturbed, except for a narrow band of quartzite-breccia dipping at a high angle landward, and crossing shales and quartzites alike. On the cliff-top south of Puck's Rocks there are good sections in unbroken quartzite interbedded with shaly breccia.

(2) Above the dark green igneous sill at the north end of Freshwater Bay, the southward-facing cliff shows alternating fine sandy and muddy beds at the rate of five or six in the thickness of a foot. These are in part wildly contorted, without reference to layers above and below, and show some of the beds breaking up into detached masses (Pl. XVII, Fig. 2). If this is any criterion, the shaly breccia most probably arose by contemporaneous slipping and brecciation, before and after which sub-parallel beds were deposited.

(3) Around Hippy Hole examples of rapidly alternating shales and silts with graded bedding are abundant. As one goes south from the Hole, a few yards before coming to the fault figured in a drawing by G. V. Du Noyer in the Dublin Memoir (1903, 70, fig. 14), one may distinguish a silty layer with current-bedding. This appears to have been formed by anomalous eddies on a sea-floor beyond the reach of normal wave-action. It proves conclusively that the Series, at this point, is "younging" towards the Baily Lighthouse. In many of the alternating layers flaky breccia fragments are included. Since these are separated by thin unbroken layers of shale and silt, they certainly do not seem to have been produced by other than contemporaneous means. West of the Needles, shaly breccia appears in great thickness and is particularly well developed in two stacks at Worn Hole. Farther north-west on this coast, between massive beds of pinkish and yellowish quartzite, the alternating light and dark green slates are practically unbrecciated.

It is concluded from (1) that brecciated quartzites and some of the unbrecciated were formed in fissures which opened after the deposition of the rest of the succession. No doubt earthquakes accompanied this process. The normal deposition of quartzites in the absence of fissures is also readily proved. At (2) we have evidence of contemporaneous slipping and brecciation. Though possible even on a slope of a few degrees, this and the sliding of large boulders may have been assisted by seismic disturbances. In the case of (3) we have to account for the widespread distribution of silty material in thin bands among pasty shales, and for the enclosure of angular shale fragments which would become rounded or be disintegrated if rolled about in the normal course of sedimentation. The only explanation seems to lie in the breaking up of the sea-floor by earthquakes and the sudden introduction of a novel matrix by tunamis.

At first it was thought that the massive quartzites were also deposited by tunamis. Some of the former are about 300 feet thick. They do not contain angular fragments of shale. Their only included fragments are the rounded pebbles reported at Kilrock by Sollas (1892, 179), in beds, however, which have fewer rounded grains than is common. The source of the immense amount of material represented in the massive quartzites, in a sea with sediments usually fine and showing a poverty of detritus available for deposition, is something of a problem. In this connection I attach great importance to the recognition of " small well-defined rounded grains of quartz " in these rocks by T. Weaver (1819, 185), and to Sollas's detailed investigation (1892, 175, etc., figs. 3, 6), which shows that in spite of the effects of pressure, grains may remain approximately circular in section, and that this rounding is found even in examples as small as 0·13 by 0·11 mm. From the observations of W. Mackie (1897, 311), V. Ziegler (1911, 654), E. B. Bailey (1924, 105), and others, it is impossible to avoid suggesting an aeolian origin for these. This may also explain why in the alternating beds there is not the volume of shore-derived sand which one would expect if the Bray Series were estuarine as G. A. J. Cole suggested (1921, 1). The truer picture seems to be of a clear sea in which deposition had been reduced to a minimum. Probably the land surface was peneplanated, either a hot or a cold desert, not yet covered by plant life,



TEXT-FIG. 1.—Section of reddish quartzite with wind-rounded grains and some magnetite. Bray Series. Roadstone quarry, Loughoreen Hills, Howth. × 50.

with migrating sand-dunes and few rivers. In storms, volumes of sand may have been carried out to sea.

In another part of the area in which these sediments were deposited, L. B. Smyth (1923, 229–233) has noted the occurrence of tiny squarish bodies. These he regards as showing the former position of pyrites cubes, but he also compares them with halite pseudomorphs, like those in Trias marls. Emphasis need not be attached to the point, but they may represent local desiccation.

So far as correlation is concerned, one may recall the association of the Bray series with part of the Mona Complex by J. F. Blake (1888, 534–6), and the records by Watts (1899, 677) and E. Greenly (1919, 79) of rounding of grains in the Gwna quartzites. These are at present assigned to late pre-Cambrian. J. G. Goodchild's argument (1897, 217) in favour of desert conditions in the Torridonian suggests itself. One may also remark on the occurrence of dreikanter pebbles in part of the Longmyndian, and on the fact that the Durness limestone, which seems to extend from Cambrian into Ordovician, accumulated in the absence of river-borne detritus. The perfect rounding of grains down at least to 0·63 mm. in diameter as figured by J. J. H. Teall (1888, pl. xlvi, fig. 1) from the Lickey quartzite, has also been pointed out to me. The latter is generally regarded by analogy with the Wrekin and Malvern quartzites as Lower Cambrian. Although the Llandovery sandstone near Birmingham has rounded grains, the majority of possible correlatives seem to rule out A. McHenry's suggestion (quoted by Lamplugh, 1903, 8) that the Bray series is as late as Silurian.

In conclusion it may reasonably be claimed that when the first signs of crustal instability manifested themselves the shores of the Lower Paleozoic geosyncline in these islands consisted in part of mature desert.

BIBLIOGRAPHY.

BAILEY, E. B. 1924. "The Desert Shores of the Chalk Seas," GEOL. MAG., LXI, 102–106.

—— 1930. "New Light on Sedimentation and Tectonics," GEOL. MAG., LXVII, 77–92.

—— and WEIR, J. 1932. "Submarine Faulting in Kimmeridgian Times: East Sutherland," *Trans. Roy. Soc. Edinburgh*, lvii, 429–467.

BLAKE, J. F. 1888. "The Monian System of Rocks," *Quart. Journ. Geol. Soc.*, xliv, 463–547.

COLE, G. A. J. 1921. "The Problem of the Bray Series," *Proc. Roy. Irish Acad.*, xxxvi, sect. B, 1–10.

DU NOYER, G. V. 1903. In "The Geology of the Country around Dublin (Explanation of Sheet 112)", *Mem. Geol. Surv. Ireland.*

GOODCHILD, J. G. 1897. "Desert Conditions in Britain," *Trans. Edinburgh Geol. Soc.*, vii, pt. 3, 203–222.

GREENLY, E. 1919. "The Geology of Anglesey," *Mem. Geol. Surv.*, i–ii.

HENDERSON, S. M. K. 1935. "Ordovician Submarine Disturbances in the Girvan District," *Trans. Roy. Soc. Edinburgh*, lviii, 487–509.

KELLY, J. 1853. "On the Quartz Rocks of the Northern Part of the County of Wicklow," *Journ. Geol. Soc. Dublin*, v, 237–262.

KINAHAN, G. H. 1878. *Manual of the Geology of Ireland*, Kegan, Paul and Co., London.
LAMPLUGH, G. W. 1895. "The Crush-Conglomerates of the Isle of Man," *Quart. Journ. Geol. Soc.*, li, 563–599.
—— 1903. In "The Geology of the Country around Dublin (Explanation of Sheet 112)," *Mem. Geol. Surv. Ireland.*
McHENRY, A., and WATTS, W. W. 1898. "A Guide to the Collections of Rocks and Fossils belonging to the Geological Survey of Ireland, arranged in the curved gallery of the Museum of Science and Art, Dublin," *Mem. Geol. Surv. Ireland.*
MACKIE, W. 1897. "On the Laws which Govern the Rounding of Particles of Sand," *Trans. Edinburgh Geol. Soc.*, vii, pt. 3, 298–311.
RYAN, W. J., and HALLISSY, T. 1912. "Preliminary Notice of Some New Fossils from Bray Head, Co. Wicklow," *Proc. Roy. Irish Acad.*, xxix, sect. B, 246–251.
SMYTH, L. B. 1923. "On a Problematic Structure in the *Oldhamia* Rocks of Bray Head, Co. Dublin," *Sci. Proc. Roy. Dublin Soc.*, xvii, 229–233.
SOLLAS, W. J. 1891. "On the Structure and Origin of the Quartzite Rocks in the Neighbourhood of Dublin," *Sci. Proc. Roy. Dublin Soc.*, vii, 169–188.
—— 1893. "The Geology of Dublin and its Neighbourhood," *Proc. Geol. Assoc.*, xiii, 91–122.
TEALL, J. J. H. 1888. *British Petrography: with special reference to the Igneous Rocks*, Dulau and Co., London.
WATTS, W. W. 1899. "Appendix—On the Microscopic Study of the Rocks of Northern Anglesey," *Quart. Journ. Geol. Soc.*, lv., 675–678.
WEAVER, T. 1819. "Memoir on the Geological Relations of the East of Ireland," *Trans. Geol. Soc., London*, v, 117–304.
ZIEGLER, V. 1911. "Factors Influencing the Rounding of Sand Grains," *Journ. Geol.*, xix, 645–654.

EXPLANATION OF PLATE XVII.

FIG.

1.—Shaly breccia with 5 ft. quartzitic boulder (centre); massive quartzite cutting across shaly breccia in right foreground and also top right, junction at hammer-head. Cliff south of Stag, Balscaddan Bay, Howth.

2.—Alternating shaly beds showing slipping and breaking up. Two later small faults shift the beds a few inches. Length of section about 8 feet. Top of cliff, near Gaskin's Leap, north end of Freshwater Bay, Howth.

For a 75 per cent. grant towards the cost of illustration thanks are due to the Carnegie Trust for the Universities of Scotland.

A Final Note on the Ebbsfleet Channel Series.

By J. P. T. BURCHELL.

BOTH geologists and archaeologists will be under a debt of gratitude to Messrs. King and Oakley for their recent paper on the Pleistocene sequence of the lower part of the Thames Valley (1).[1] Not only have they conveniently summarized the results obtained by other field-workers, but they have contributed two postulates of great importance. These are: (*a*) the probability of a major period of erosion between the deposition of the Lower Loam and the

---

[1] The figures in parentheses relate to References at end of article.

Middle Gravel of the Boyn Hill Terrace succession; and (*b*) the recognition of a period of erosion between the formation of the Lower Flood Plain Gravel and the Post-Pleistocene alluvial beds.

On page 62 of their paper there appears the statement that I "would refer all the Pleistocene peats of the Lea Valley to the Middle Terrace", and GEOL. MAG., 1935, LXXII, 331, is quoted in support of this remark. Lest a mistaken impression be gained, I take this opportunity of recording that throughout the article referred to I have made no mention of the Ponders End Stage in connection with the Middle Terrace; instead I relegated the Ponders End Stage to the Crayford Gravel Terrace. In the text of my note it is clearly set out that the Crayford Gravel Terrace is younger than the Crayford Brickearth Series; whilst the Geological Survey Map (Dartford, Sheet 271, scale 1 m. to 1 in.) accompanying the Dartford District Memoir likewise shows the Crayford Gravel Terrace as a member of the Flood Plain Series and not of the Middle Terrace. Similarly the Hedge Lane gravel to which I referred has been mapped by the Geological Survey (North London, Sheet 256, scale 1 m. to 1 in.) as Flood Plain Gravel and not as Middle Terrace. The height to which both the Crayford Gravel Terrace and the Hedge Lane gravel in question attain and the fact that Trail overlies each indicates an Upper Flood Plain age for these two sets of gravels. Further, I quoted the official geological opinion that the Crayford Gravel Terrace is separated from the Low Terrace—i.e. Lower Flood Plain. This opinion has recently been confirmed by excavations conducted by me in Stone Court Valley (2), which indicate that the Crayford Gravel Terrace is separated from its overlying Trail by the period of erosion responsible for the cutting of the Buried Channel, and that subsequent to the formation of this Trail the gravels of the Lower Flood Plain were deposited.

The comprehensive and definite results I am obtaining in the Ebbsfleet Channel have caused me to regard the uppermost loam of that section as the lateral valley equivalent of the Upper Flood Plain deposits of the main valley.

Writing of this loam on page 66, Messrs. King and Oakley state: "The loam may well have been deposited during the period of melting represented by the fluviatile gravels of the Upper Flood Plain Terrace. . . . but is probably more of the nature of a hill-wash than a river 'alluvium'."

I am much surprised at such an expression of opinion as to the nature of the deposit and I can only attribute it to an incomplete examination of the bed in the field. For the material comprising the uppermost loam consists of a faintly stratified, fine sandy, and stoneless loam which reveals, at intervals, thin, horizontally deposited, layers of clay and sand. Occasionally a thin, horizontal, line of minute stones may be observed in the loam. It would be hard to instance a deposit more dissimilar to a hill-wash, so many examples of which are available for study in the neighbourhood.

I have mentioned elsewhere that the base-level of the uppermost, fluviatile, loam of the Ebbsfleet Series may be traced from 50 feet above O.D. to 5 feet below O.D. (3); it has now been proved at 10 feet below O.D.

This year's investigations in the Ebbsfleet Valley and in Brook Vale have established that the denuded remains of the uppermost Coombe Rock or Trail are preserved here and there in the low level where, as at the high level, it overlies the uppermost loam. Further, the containing-cliff to the Buried Channel of pre-Lower Flood Plain age is comprised of these beds.

Some years ago I recorded the discovery of sub-aerial loams (younger series) in which occurred flint implements and occasional fragments of coarse pottery (4). Excavations recently undertaken in Brook Vale and in the Bean–Greenhithe valley have proved that the earliest of these loams, No. 1 (numbering seven in all), immediately succeeds the uppermost Coombe Rock or Trail. Furthermore, there is a close relationship between this loam and the Coombe Rock in question, which is evidenced by the interdigitation of the two deposits and the nature of the molluscan fauna contained in the loam. Shells are scarce in the deposit and are restricted to *Pupa muscorum* Linn. and *Vallonia costata* Müll.: a fauna identical with that of the Middle Loam (sub-aerial—older series) of Mid-Pleistocene age. In sub-aerial loam No. 2 the number of molluscan species increases and *Helicella striata* Müll. appears. In loam No. 3 the number of molluscan species is further increased, and *Pomatias elegans* Müll. and *Cepoea nemoralis* Linn. make their first advent. In loam No. 4 *Helicella striata* Müll. makes its final appearance. With the commencement of the formation of sub-aerial loam No. 5 climatic conditions had reached an optimum, for not only do the shells attain their greatest number of species, but artefacts and pottery fragments are met with for the first time in the series, associated with bone in a mineralized state of preservation. Loam No. 7 appears to be in the nature of a "limon de lavage": it is non-calcareous and this factor makes it impossible to estimate its former molluscan content.

These sub-aerial loams of the younger series pass imperceptibly from one to the other and, in the Bean–Greenhithe valley, they attain a thickness of over 4 feet. Subsequent to their formation the Bean valley was excavated, with the result that, in its central part, these loams have been completely eroded away. Following upon this erosion the newly-excavated valley became choked with a stony hill-wash, which is now decalcified. Overlying the decalcified hill-wash is an accumulation of calcareous hill-wash overlain by surface soil. This evidence suggests that the sub-aerial loams accumulated *pari passu* with the deposition of the Lower Flood Plain gravels; a suggestion which has lately been confirmed in Stone Court valley, where I have found a similar flint industry occurring in "rafts" in the gravel of the Lower Flood Plain. These specimens, which are entirely unrolled, occur in groups locally in the gravel surrounded by a sandy matrix. It would seem that a "floor" had been disturbed higher up the valley and the remnants became incorporated whilst in a frozen state in the gravel. In Brook Vale there is evidence for regarding the sub-aerial loams of the younger series as having been truncated during the excavation of Buried Channel "B". Occupying the surface of the Lower Flood Plain gravel and underlying stony alluvium is a "floor" of Early Magdalenian age, yielding a prolific "raclette" industry resembling that described from Badegoule in the valley of the Vézère (2).

Investigation of the left part of the Ebbsfleet Channel having been completed, attention has been directed to the central portion of the channel. Here three new beds have been added to the base of the succession already established (5). Excavation has revealed that this channel was originally cut during the period of erosion which preceded the formation of the Main Coombe Rock. Subsequently the Main Coombe Rock occupied the channel. Erosion occasioned during the ensuing melt-water stage re-cut the channel, removing the Coombe Rock save in the central portion, whilst coarse, unstratified, melt-water gravel accumulated upon the denuded remnant of Coombe Rock.

The melt-water gravel phase was succeeded by a period of sand deposition. On the surface of this sand, which contains *Bithynia tentaculata* Linn. and a microtine fauna, there occurs a "floor" yielding hand-axes, cores, and flake-implements of Clacton and Levallois types in an unrolled and unpatinated condition (6), accompanied by the remains of mammoth, rhinoceros, horse, etc. Then follows the succession of deposits already described (5).

I am hoping, by the end of next year, to be in a position to furnish a detailed account of the results I shall have obtained in the five adjacent lateral valleys now under investigation. In the meanwhile I attach hereto a tentative summary of the evidence to date which I have been able to accumulate through the financial assistance so generously afforded by the Trustees of the Percy Sladen Memorial Fund, the Royal Society, and B. W. Horne, Esq., and the facilities offered by the owners of the land—the Associated Portland Cement Manufacturers.

REFERENCES.

(1) King, W. B. R. and Oakley, K. P. "The Pleistocene Succession in the Lower Part of the Thames Valley," *Proc. Prehist. Soc.*, 1936, N.S., ii, 52–76.

(2) Burchell, J. P. T., "An Early Magdalenian 'Raclette' Industry in the Lower Thames Valley," *Nature*, 1936, cxxxviii, 79.

(3) —— "Evidence of a Late Glacial Episode within the Valley of the Lower Thames," Geol. Mag., 1936, LXXIII, 91–2.

(4) —— *Archaeologia*, 1933, lxxxiii, 67–80.

(5) —— "Evidence of a further Glacial Episode within the Valley of the Lower Thames," Geol. Mag., 1935, LXXII, 90–91.

—— "Evidence of a Late Glacial Episode within the Valley of the Lower Thames," Geol. Mag., 1936, LXXIII, 91–2.

(6) —— "Hand-axes later than the Main Coombe Rock of the Lower Thames Valley," *Antiq. Journ.*, 1936, xvi, No. 3, 260–4.

Lateral Valleys—Lower Thames.	*Main River—Lower Thames.*	*Culture and Climate.*		*Correlation.*
Hill-wash, Alluvium.	Infilling of Buried Channel " B ".	Medieval, Roman, Iron age, Bronze Age, Neolithic,	Temperate,	
		Mesolithic, Magdalenian.	Boreal.	Broxbourne, peat bed.
Hill-wash due to solifluction.		Magdalenian.	Cold.	—
	Erosion of Buried Channel " B ".			
Sub-aerial loams (younger series).	Infilling of Buried Channel " A ", and deposition of Lower Flood Plain gravel.	Latest Levalloisian.	Cool, Temperate,	Kelsey Hill, peat bed.
			Very cold.	—
Coombe Rock, and/or Trail.	Coombe Rock, and/or Trail.	—	Very cold.	—
	Erosion of Buried Channel " A ".			
Uppermost loam—fluviatile, cailloutis at base.	Deposition of Upper Flood Plain gravel.	Levalloisian.	Cold.	Ponders End Stage.
Coombe Rock, and/or Trail.			Very cold.	—
	Pre-Upper Flood Plain erosion period.			
Upper loam—flood loam.		—	Warm.	Kirmington, peat bed.
Middle loam—sub-aerial, (older series).		—	Very cold.	—
Coombe Rock, and/or Trail.	The Ebbsfleet Channel Series is but imperfectly represented in the Crayford and Erith district.	—	Very cold.	—
Middle loam—sub-aerial, (older series).		—	Very cold.	—
Lower loam—fluviatile.		—	Cool.	—
Gravel—fluviatile.		Levalloisian, Clactonian, and Hand-axes.	Cool.	—
Lowermost loam—fluviatile.	—	—	Cool.	—
Melt-water gravel of Main Coombe Rock.	—	—	Very cold.	—
Main Coombe Rock.	Main Coombe Rock.	—	Very cold.	—
Pre-Main Coombe Rock erosion period.	Pre-Main Coombe Rock erosion period.	Levalloisian of Baker's Hole.	Temperate, becoming cold.	—

REVIEWS.

RUTLEY'S ELEMENTS OF MINERALOGY. By H. H. READ. 23rd edition, revised and enlarged; pp. viii + 490, with 128 text-figures. London: Thomas Murby and Co., 1936. Price 8*s*.

SINCE the fundamental changes introduced in the edition of 1915, alterations in successive editions of this well-known textbook have mainly been concerned with statistical data. A complete resetting of the text has now afforded Professor Read the opportunity for further important alterations. An increase of a hundred in the number of pages, each of which now contains more matter, affords space for extensive additions. The chapter on the Elements of Crystallography has been largely rewritten, and is now nearly double the length of those sections of the earlier editions which it replaces. (An obscure sentence survives on p. 65, where it appears to be suggested that each of the thirty-two classes possesses three elements of symmetry; it is desirable, too, that the student should be taught from the outset to observe rigidly the conventional use of smooth, curly, and square brackets as face-, form-, and zone-axis symbols respectively.) The discussion of the Optical Properties of Minerals has been expanded to afford a complete basis for work with a petrographic microscope, including the simpler types of interference figures. The Glossary is replaced by an interesting new chapter on the Occurrence of Minerals, presenting the vital information in a much more readable form. In Part II, the Descriptions of Minerals, a classification based on the Periodic Table gives a logical arrangement to the whole section, whilst preserving interest in the economic aspect. The rock-forming silicates are treated together, and the descriptions include the optical data necessary for their identification in thin section; their compositions are explained in terms of the hypothetical silicic acids, and the findings of structural analysis are not taken into account, the amphiboles for example still being quoted as simple metasilicates.

Many excellent new figures have been added, chiefly in the chapters on crystallography and crystal optics, with a few illustrations of thin sections in Part II, whilst some of the less satisfactory figures of the earlier editions have been redrawn. (Fig. 74 should be improved in a future edition, the rays appearing to be refracted away from the normal on passing into the more dense medium; probably the explanation of the Becke effect most readily appreciated by students is that advanced by Anderson and Grabham, in terms of an inclined boundary and normal illumination.) The many alterations and additions combine to extend the usefulness of "Rutley" whilst maintaining the general character of the original work; there is certainly no other textbook of similar scope available at the very reasonable price at which this enlarged edition is offered.

F. C. P.

GREAT EARTHQUAKES. By CHARLES DAVISON. 8vo, pp. xii + 286, with 12 plates and 97 figs. London: Murby and Co., 1936. Price 17*s.* 6*d.*

DR. DAVISON'S new book deals with sixteen great earthquakes, from the Lisbon one of 1755 to the Hawke's Bay one of 1931; his study of the Tokyo earthquake of 1923 may be regarded as a supplement. In each case he gives a seismic history of the region, which introduces information for other important shocks. He discussed also the foreshocks, if any, the aftershocks, associated sea waves, and the geological effects. The latter, involving fault scarps, landslips, pools produced by subsidence, and horizontal displacements, are illustrated by numerous excellent photographs. The literature used is very scattered, and the author deserves our gratitude for presenting it in a compact form.

In places, however, he seems to be insufficiently critical. There is a reference (p. 142) to visible waves in the ground, travelling "faster than a man could walk, though not so fast as he could run". The speeds of the waves recorded instrumentally in earthquakes are some kilometres a second. In the small North Sea earthquake of 1931, however, buildings in Cambridge were seen to sway about in a way that would have torn every one of them to pieces had the motion been real. It appears that a small but rapid felt vibration of the ground can lead to a disturbance of vision. Lights of various colours, brightnesses, and shapes are also recorded as seen during earthquakes; Dr. Davison accepts these as physical without any reference to the well-known phenomenon of "seeing stars".

Not enough use is made of what we know from instrumental sources. The chief sudden movements in an earthquake at short distances are the pulses known as Pg and Sg, each followed by a train of waves. In the former the ground moves in the direction of travel of the waves or opposite to it. In the latter (Sg), which is the larger, it may move in any direction, but the largest component is usually across the direction of travel. But on p. 48, Davison, quoting Mercalli, accepts without question the statement that the two principal phases of the felt movement, in an Italian earthquake, being in different directions, came from different foci. For the San Francisco earthquake, a map is given showing the directions of the movement, mostly inclined to the fault at small angles. We should expect this, since the chief part of the displacement was a horizontal gliding along the fault, so that the horizontal displacement across the direction of travel should be much the largest part of Sg. Yet apparently these directions are taken as referring to Pg. On p. 85 we learn that for the Valparaiso earthquake of 1906 "as is usual in great earthquakes the duration of the shock was considerable, at Copiapo amounting, it is said, to as much as 10 minutes". The distance, from the map, is about 450 miles, or 720 km. We may compare the Strasbourg record of the small Jersey earthquake at a similar distance, which shows disturbance for quite this time. The duration mentioned is, of course, that for which the motion was strong enough to be felt; this would naturally be longer in a strong earthquake, without there being any difference in the duration for which the disturbance was more than a given fraction of the maximum displacement.

Useful information is given towards the end of the book about the frequency of aftershocks, which is high after a great earthquake and proceeds to die down asymptotically. The author goes on, however, to find various periodicities in the frequency, superposed on this general variation. Now it is well known that any random series analysed for a periodic variation will show it; the crucial question is whether the variation found is greater than we should expect in a random series. Enormous numbers of alleged periodicities have been published, mostly without the slightest attempt to test this point, and in very few cases has later work shown them to pass the most elementary test. It must be said that Dr. Davison is one of the few that have applied any sort of test, but I seriously doubt whether his test is sufficiently stringent. The point is that when the number of events tested for periodicity is increased, the harmonic variation, if there is one, remains the same, but the expected amplitude produced by random variation in the distribution decreases as the inverse square root of the number of *independent* occurrences. Davison shows convincingly that an earthquake tends to be followed by others after a few minutes or hours; but this implies in turn that earthquakes separated by a short interval of time are not to be regarded as independent, and the number of independent occurrences is very much less than the whole number of earthquakes. His estimate of the random variation assumes all earthquakes independent, and if this is corrected the probable accidental amplitude will be much increased. It is very doubtful whether any of the periodicities will survive if this is allowed for.

Allusion is made (p. 144) to pillars found after an earthquake to have rotated about a vertical axis, as if this involved a complicated movement of the ground in various directions. No motion of the ground could produce rotation if the point of support remained under the centre of gravity. But if the last piece of mortar to become detached is not exactly under the centre of gravity we should expect rotation, the pillar acting as a horizontal seismograph. Overturning is, of course, another matter. Davison uses the dimensions of overturned bodies to give interesting estimates of the horizontal acceleration.

I have dwelt on the shortcomings of the book mainly because it is an important work, and in a subject where several kinds of evidence are available it takes a correction a long time to catch up with a mistake. The amount of useful material given is very large, and the book can be recommended to anybody who wants to know what goes on near the epicentre of a large earthquake.

H. J.

The Earth's Magnetism. By Professor S. Chapman. pp. xi + 116, with 35 figures. Foolscap 8vo. London: Methuen & Co., 1936. Price 3*s*. 6*d*.

PROFESSOR CHAPMAN has written an interesting popular account of terrestrial magnetism, dealing with the permanent field, the secular variation, the solar and lunar variations, and magnetic storms. One impression made on the reviewer is the lack of correspondence between the results and anything we know about the solid earth. There are many well-established relations between terrestrial magnetism and the sun and the earth's atmosphere, though it cannot be said that understanding of them is complete. Apparently the short period variations and storms are the result of electric currents produced in various ways in the atmosphere; the direct effects of the magnetic fields of these are modified by those of induced currents in the body of the earth. These give some information about the electrical conductivity of the interior, which apparently rises rather rapidly at more than 160 miles in depth. It would be interesting to know whether this can have any relation to the increase of density and elastic moduli inferred from seismology at a depth of about 480 km.; the present estimates differ widely, but it is not clear how much alteration of Chapman's estimate would be permissible. No decided opinion is expressed about whether the permanent field is due to permanent magnetization or to electric current travelling around the magnetic axis. And why the secular variation? Present knowledge suggests that the magnetic poles complete a circuit about some not clearly identified point in about 480 years, a most odd period, much too long to agree with any elastic or electrical free vibration, or any obvious astronomical period, and much too short to agree with any suggested geological period. If the field is due to currents, why are they not strictly about the axis of rotation, as a dynamo theory would require? If it is due to magnetized particles why should their magnetic axes precess in this weird way? Perhaps the induction due to a dynamo effect would tend to produce such a phenomenon. But even then the mean position of the magnetic axis might be expected to coincide with the axis of rotation, and the mean declination at all places would be zero. But from one of Chapman's diagrams it appears that the mean declination at Greenwich is about 8° west.

The author is the master of his subject, and the book can be recommended to anybody wanting a compact account of what is known.

H. J.

REPORTS AND PROCEEDINGS.

Mineralogical Society.

5th November, 1936.

(1) " Demonstrations in petrogenesis from Kiloran Bay, Colonsay. 1. The transfusion of quartzite." By Miss D. L. Reynolds. (With analyses by Lady Agnes Gibbs and others.)

The hornblendite of three small composite intrusions is thickly sprinkled with blocks of white quartzite, most of which exhibit various stages of replacement by micropegmatite, syenite, and appinite. The syntectic rock types, which present an igneous appearance, occur in individual xenoliths either separately or in concentric zones. In the latter case micropegmatite or syenite adjoins the centrally placed residual core of quartzite. The boundaries between the residual quartzite and its replaced portion and between successive replacement zones are always sharp. Completely replaced xenoliths are represented by felspathic patches and schlieren. By study of successive replacement zones and chemical analysis, it is found that the process of replacement involved the differential diffusion of various magmatic constituents (possibly ionic) into the quartzite, some constituents having actually become concentrated in the metasomatic rocks.

Finally, the process of transfusion gave rise to syntectic magma, of syenitic and appinitic composition, now represented by veins which emerge from metasomatized quartzite.

(2) " Transfusion of quartz xenoliths in alkali basic and ultrabasic lavas, south-west Uganda." By Professor Arthur Holmes (with microchemical analyses by Dr. Hecht).

Many of the lavas of south-west Uganda contain augite-rimmed xenoliths of transfused quartz. Transfusion begins with the development of intergranular channels of glass and continues until only isolated relics of quartz remain. Refractive indices : glass from various xenoliths, 1·472 to 1·497 : pure silica-glass, 1·458. In order to ascertain what constituents migrated from magma to quartz, Dr. F. Hecht has made microchemical analyses of three samples of glass from pure quartzite or vein-quartz, occurring in two murambites and a katungite from the Bufumbira district.

Analyses of these new rock-types are presented. Murambite is melanocratic leucite-absarokite, katungite is potash-rich pyroxene-free olivine-melilitite. The results show that in all three rocks the glass has the composition of silica-rich potassic obsidian. The constituents introduced were mainly Al_2O_3, K_2O, and H_2O, accompanied by smaller amounts of Na_2O, TiO_2, P_2O_5, MnO, and the cafemic oxides. SO_3 was a notable contribution from murambite and CO_2 from katungite.

(3) " An occurrence of greenalite-chert in the Ordovician rocks of the southern uplands of Scotland." By Dr. W. Q. Kennedy.

A dark-green to black cherty rock from the Arenig outcrop near Glenluce. Wigtownshire, is found to consist of rounded or irregular granules of a greenish, isotropic, amorphous mineral embedded in a fine-grained base of cherty silica. The optical properties, nature of the alteration, and composition of the rock indicate that the mineral is a pure hydrated ferrous silicate, identical with the greenalite occurring in the Biwabik iron formation of Minnesota.

(4) "The composition and paragenesis of the biotites of the Carsphairn igneous complex." By Mr. W. A. Deer (communicated by Professor C. E. Tilley).

Three biotites have been analysed from the granites, tonalite, and hornblende hybrid of the Carsphairn intrusion. Their compositions are closely related to the enclosing rock when the mineral has crystallized under normal magmatic conditions. During the hybridization process this relationship is less strong due to changing equilibrium conditions. Their structural formulae, derived from partial X-ray analysis, have been calculated, and the formula suggested by Pauling is accepted in preference to Mauguin's. The X*n* group (co-ordination number 6) varies from $n = 2{\cdot}5$ to 3. In biotites from the intermediate rocks *n* approaches 3, and the mica becomes richer in the phlogopitic molecule. The biotites are related as members within a single intrusion and show characteristic features distinguishing them from biotites of other complexes.

CORRESPONDENCE.

THE AUGITE-BIOTITE-DIORITE OF THE NEWRY COMPLEX

Sir,—In the October number of the Geological Magazine Professor Shand takes exception to certain statements of mine about the rocks of Slievegarron, which I have called augite-biotite-diorite. Before proceeding to discuss the main point at issue, I frankly confess to an error of omission. My statement that the analysed rock is "undersaturated", to which Professor Shand rightly objects, should, of course, have read "normatively undersaturated". That the rock really is undersaturated in this chemical sense is shown by the appearance in the norm of 6·25 per cent. of nephelite and 15·73 per cent. of olivine. I cannot, however, resist the temptation to point out that in the very act of protesting Professor Shand commits a precisely similar offence. He refers to augite-biotite-diorite as "diorite", which it certainly is not. Fortunately the matter is less serious than if a chemist referred to nitro-glycerine as glycerine.

The real question is that of the name which should be given to the rock under discussion. The rock is the predominant member of a series which ranges from biotite-pyroxenite to andesine-rich types. Mineralogically, it is accurately described as *augite-biotite-diorite*, since in addition to augite and biotite the essential minerals are andesine and hornblende.

Although one-quarter of the rock is made up of biotite and the plagioclase is An_{35}, the rock becomes a soda gabbro in Professor Shand's classification. Perhaps the incongruousness of a *potash* soda gabbro leads Professor Shand to desert the facts and agree with Professor Bailey "that gabbro-diorite is the most appropriate name for the rock". It is very easy to show that the rock is not a gabbro-diorite. In Tröger's *Kompendium*, p. 146, we learn that the term gabbro-diorite was introduced by Törnebohm for normal gabbro with uralitic hornblende, and that by later authors it has been adopted both for plagioclase-rich gabbro (= ossipite) and for rocks which chemically and mineralogically stand midway between diorite and gabbro. The augite-biotite-diorite of Slievegarron is demonstrably none of these things. It is not a normal gabbro for its plagioclase is An_{35}; it is not plagioclase-rich, for it actually contains less plagioclase than typical gabbro; and far from standing between diorite and gabbro it stands, both chemically and mineralogically, between plagioclasite and biotite-pyroxenite. Obviously the rock is not a gabbro-diorite, and the very modes cited by Professor Shand show that it is not, though by failing to quote the figures for biotite he hides the real contrast. Yet Professors Bailey and Shand, both members of the B.A. Committee on Petrographic Classification and Nomenclature, not only pronounce the rock to be a gabbro-diorite, but go out of their way to proclaim their opinion to the world.

The Slievegarron rocks under discussion do not differ from gabbro in the direction of diorite, but in the direction of alkali-rich gabbro. The suggestion that they might be described as biotite-essexite-gabbro was intended to emphasize this alkaline character of the rocks, with a view to drawing attention to a significant difference from gabbro-diorite. The suggestion arose from the observation that texturally, as well as mineralogically and chemically, the rocks bear a remarkable resemblance to others which have been described as essexite or essexite-gabbro. It may be noted in passing that the term essexite does not exclude andesine, and that a rock is none the less alkaline because a considerable proportion of its alkali is potash. Chemically, the rock falls comfortably into Niggli's essexite-gabbro magma group, as the following figures show :—

	si	*al*	*fm*	*c*	*alk*	*k*	*mg*
Augite-biotite-diorite .	114·5	23	43	21·5	12·5	·30	·61
Essexite-gabbro magma	105	23	43	24	10	·25	·45

Niggli himself points out that in the gabbro-diorite magma group the *si* values are higher (average 135) and the *alk* values (for corresponding values of *si*) lower than in the essexite-gabbro magma group. Here is further proof that the augite-biotite-diorite is not a gabbro-diorite.

A biotite-augite-diorite from Predazzo is precedent for the term augite-biotite-diorite, and it may be noted that although the Predazzo rock is considerably less rich in alkalies (Slievegarron, 6·31; Predazzo, 4·36 per cent.), yet it also falls into Niggli's essexite-gabbro magma group. Professor Shand does not give any reason for objecting to my use of the name augite-biotite-diorite. The only one I can think of which he may have had in mind is that the rock contains more than 30 per cent. of coloured minerals, and so lies outside the group of rocks which he calls " soda diorite ". As to this it is only necessary to remark that the rock has not been called " soda diorite ", and that the artificial limitation which applies to " soda diorite " does not by any means apply to diorite or to augite-biotite-diorite.

As to the meaning which I attach to the term augite-biotite-diorite, I think I have explained this as clearly as even Professor Shand could wish by providing a detailed description of the rock, accompanied by a mode, a chemical analysis, a norm, and a figure. If Professor Shand or any other " student of rock names " objects to the term because of the relatively high proportion of mafic minerals, and to the alternative " biotite-essexite-gabbro " because the alkali mineral is biotite instead of nepheline or aegirine, then there will be an obvious case for coining a new name.

DORIS L. REYNOLDS.

THE UNIVERSITY,
DURHAM.
10th October, 1936.

INDEX.

AKPATOK Island, Cephalopods from, the late A. F. Foerste and I. H. Cox, 289.
Al-atoms, rôle of, in the two reaction series, A. Brammall, 144.
Albian Ammonoids of Folkestone, R. Casey, 444.
Allison, A., Tertiary Dykes of Craignish, Argyll, 73.
Ammonite Terminology, L. F. Spath, 334.
Anderson, E. M., Type Fossils in Roy. Scottish Museum, 427.
Anderson, J. G. C., Age of the Girvan-Ballantrae Serpentine, 535.
Anthraconauta phillipsi in the Denbighshire Coalfield, H. H. Simpson, 278.
Ardgour Marble, Symplectite-bearing Nodules in, H. I. Drever, 448.
Arkell, W. J., The Purbeck and Ridgeway Faults, Dorset, 56, 97.
Augite-Biotite-Diorite, Definition of, S. J. Shand, 479.
— — D. L. Reynolds, 560.

BAAK, J. A., Petrology of Southern North Sea, 283.
Bababudanite, B. Rama Rao, 192.
— C. S. Pichamuthu, 335.
— from Mysore, India, C. S. Pichamuthu, 39.
Bailey, E. B., Ballachulish Lag, Loch Leven, 412.
— — Newry Igneous Complex, 267.
— — Tectonic Essays, 94.
Baker, H. A., An Undiscovered Coalfield, 93.
Ballachulish Lag, Loch Leven, E. B. Bailey, 412.
Balsillie, D., Leucite-Basanite in East Lothian, 16.
Banffshire, Dalradian Rocks of, H. H. Read, 468.
Barber, C. T., Effect of Heat on Plagioclase Felspars, 286.
Barnard, J. E., Practical Photo-Micrography, 427.
Bartrum, J. A., Spilitic Rocks in New Zealand, 414.
Basal Complex in Jamaica, C. A. Matley, 331.
— — — C. T. Trechmann, 251, 382.
Benson, W. N., Ordovician Rocks, New Zealand, 241.
Blake, G. S., Geology of Palestine, 239.
Brammall, A., Gold and Silver in crystalline rocks, Malvern Hills, 144.
— — Malvernian Hornblendes, 286.
— — The rôle of Al-atoms in the two reaction series, 144.
Bray Series at Howth, A Lamont, 546.
Brighton, Raised Beach at, the late B. Smith, 423.
Bristol and Gloucester District (British Regional Geology), F. B. A. Welch and R. Crookall, 142.
British Association Committee on Petrographic Nomenclature, 319.
— Regional Geology, Bristol and Gloucester District, 142.
— — — Midland Valley of Scotland, 528.
— — — North Wales, 141.
— — — South-West England, 45.
— Somaliland, Petrology of, J. Parkinson, 365.
Brock, R. W., the late, Pre-Cambrian of the Canadian Shield, 119.
Bruce, E. L., Heavy Accessories of Certain pre-Cambrian Intrusives 193.
Brydone, R. M., Chalk at Trimingham, 479.
— — Purbeck Fault, 329.
Bubnoff, S. von, Geology of Europe, 280, 428.
Bulman, O. M. B., *Rhaphidograptus*, a new Graptolite Genus, 19.
— — The Structure of *Oncograptus*, 271.
Burchell, J. P. T., Late Glacial Episode, 91.
— — Ebbsfleet Channel, 550.
Butler, A. J., *Cymatelasma*, new Genus of Silurian Rugose Corals, 516.
Butterfield, J. A., Outgrowths on Zircon, 511.

CAMBRIAN Faunas of Australia, F. W. Whitehouse, 430.
Canada, pre-Cambrian geology in, the late R. W. Brock, 119.

Canadian Shield, Heavy Accessories of Certain pre-Cambrian Intrusives, E. L. Bruce and W. Jewitt, 193.
Carboniferous Crinoids, New Scottish, J. Wright, 385.
Carroll, D., Soils of Western Australia, 503.
Carsphairn Igneous Complex, W. A. Deer, 560.
Casey, R., Albian Ammonoid Faunas of Folkestone, 444.
Cephalopods and a *Beatricea* from Akpatok Island, the late A. F. Foerste and I. H. Cox, 289.
Ceylon, Fossil Vertebrates from, P. E. P. Deraniyagala, 316.
Chaetetes akpatokensis sp. nov., 441.
— — Ordovician species of, K. P. Oakley, 440.
Chalk at Trimingham, R. M. Brydone, 479.
Chapman, S., The Earth's Magnetism, 558.
Clark, J. G. D., Mesolithic Settlement of Northern Europe, 327.
Clough Memorial Research Fund, 48.
Coal Measures of Scotland, A. E. Trueman, 287.
Coalfield, an Undiscovered, H. A. Baker, 93.
— N. Wales, Fish Remains from, A. Wood, 481.
Coccosteus, Endocranial Structures in, E. S. Hills, 213.
Cochliodont, *Helodus simplex*, J. A. Moy-Thomas, 488.
Conglomerates, Nomenclature of, L. L. Fermor, 333.
Contrasted Differentiation, A. Holmes, 228.
— — S. R. Nockolds, 529.
Copper Resources of the World, 284.
Corundum in S. Africa, W. Kupferburger, 190.
Cox, I. H., Cephalopods from Akpatok Island, 289.
Craignish, Argyll, Tertiary Dykes of, A. Allison, 73.
Crinoids, New Scottish Carboniferous, J. Wright, 385.
Cymatelasma, a new Genus of Silurian Rugose Corals, D. Hill and A. J. Butler, 516.
— gen. nov., 516.
— *carinatum* sp. nov., 519.
— *corniculum* sp. nov., 518.
— *multiseptatum* sp nov., 517.
— *tardens* sp. nov., 520.

DALBEATTIE "Granite", A Xenolithic Pegmatite in, M. MacGregor, 171.
Dalradian Rocks of Banffshire, H. H. Read, 468.
Davies, A. M., Tertiary Faunas, 326.
Davison, C., Great Earthquakes, 556.
Deer, W. A., Carsphairn Igneous Complex, 560.
Denudation-Chronology in S. England, S. W. Wooldridge and J. F. Kirkaldy, 1.
Deraniyagala, P. E. P., Fossil Vertebrates from Ceylon, 316.
Drever, H. I., Symplectite-bearing Nodules, 448.
Drugman, J. L. E., Unusual Twin-laws in Potash-felspars, 329.
Dryden, L., Spiral Concretions and Boring Organisms, 47.

EARLE K. W., Geological Map, 327.
Earth-Movements, Ice Ages, and Faunas, A. T. Hopwood, 185.
Earthquakes, C. Davison, 556.
Earth's Magnetism, The, S. Chapman, 558.
Ebbsfleet Channel Series, J. P. T. Burchell, 550.
Eckermann, H. von, The Loos-Hamra Region, 379.
Enderbite, a new member of the Charnockite Series, C. E. Tilley, 312.
Endoceras coxi sp. nov., 292.
— *akpatokense* sp. nov., 294.
Endocranial Structures in *Coccosteus*, E. S. Hills, 213.
English, G. S., Minerals for Beginners, 240.
Eulysites and related rock types, C. E. Tilley, 144.
European Geology, S. von Bubnoff, 280, 428.

FERMOR, L. L., Nomenclature of Conglomerates, 333.
Fish Remains from N. Wales Coalfield, A. Wood, 481.
Foerste, the late A. F., Cephalopods from Akpatok Island, 289.
Frebold, H., Geology of Spitzbergen, 92.

GADABURSI Country, British Somaliland, Petrology of, J. Parkinson, 365.

Geological Map, K. W. Earle, 327.
— Society of London, award of medals, 144.
— — — Officers for 1936, 144.
— Survey of India, Index to Records, T. H. D. La Touche, 429.
Girvan-Ballantrae Serpentine, Age of, J. G. C. Anderson, 535.
Glen Shee, Minor Intrusions of, W. O. Williamson, 145.
Gold and Silver in crystalline rocks, Malvern Hills, A. Brammall and D. L. Dowie, 144.
Goldfields of Western Australia, Soils of, D. Carroll, 503.
Greenalite-chert in Ordovician rocks, W. Q. Kennedy, 559.
Greenland, Geology of, L. Koch, 96.

HANSON-LOWE, J., River Profiles and Denudation-Chronology, 287.
Hartley, J. J., Age of Igneous Rocks of Slieve Gallion, 226.
Hawkins, A. C., Book of Minerals, 141.
Helodus simplex, structure and affinities of, J. A. Moy-Thomas, 488.
Hill, D., *Cymatelasma*, new Genus of Silurian Rugose Corals, 516.
Hills, E. S., Endocranial Structures in *Coccosteus*, 213.
— — Zoning in Plagioclase Felspars, 49.
Holmes, A., Contrasted Differentiation, 228.
— Newry Igneous Complex, 334.
— Transfusion of quartz xenoliths, 559.
Hopwood, A. T., Earth-movements, Ice Ages, and Faunas, 185.
Hutton, C. O., The Morven meteorite, New Zealand, 143.
Hydraulic Limestones of the Lower Lias, P. E. Kent, 476.

ICE Ages, Faunas, Earth-Movements, A. T. Hopwood, 185.
Igneous Complex, Newry, E. B. Bailey, 267.
— — — A. Holmes, 334.
— Rocks of Slieve Gallion, J. J. Hartley, 226.
International Conference of Quaternary Research, 240.
Invertebrate Paleontology, W. H. Twenhofel and R. R. Shrock, 326.

JAMAICA, Basal Complex in, C. A. Matley, 331.
— — — C. T. Trechmann, 251, 382.
Jewitt, W., Heavy Accessories of Certain pre-Cambrian Intrusives, 193.

KAVIRONDO District, Kenya Colony, Geology of, W. Pulfrey, 26.
— Geology of, E. J. Wayland, 330.
Keble, R. A., Ordovician Rocks, New Zealand, 241.
Kennedy, W. Q., Greenalite-chert in Ordovician rocks, 559.
Kent, P. E., Hydraulic Limestones of the Lower Lias, 476.
Kenya, Geology of the Kavirondo District, W. Pulfrey, 26.
Kirkaldy, J. F., River Profiles in S. England, 1.
Klerksdorp-Ventersdorp Area, Geology of, L. T. Nel, 191.
Knight, B. H., Road Aggregates, 427.
Koch, L., Geology of Greenland, 96.
Kraus, E. H., Mineralogy, 429.
Kupferburger, W., Corundum in S. Africa, 190.
Kyanite-Eclogites, Paragenesis of, C. E. Tilley, 328.

LAMONT, A., Bray Series at Howth, 546.
Lamprophyre, Jersey, The South Hill, H. G. Smith, 87.
Late Glacial Episode, Lower Thames Valley, J. P. T. Burchell, 91.
Laterite, J. B. Scrivenor, 432.
La Touche, T. H. D., Index to Records Geol. Survey of India, 429.
Leucite-Basanite in East Lothian, D. Balsillie, 16.
Limestones of the Lower Lias, P. E. Kent, 476.
Loos-Hamra Region, H. von Eckermann, 379.

MACGREGOR, M., Xenolithic Pegmatite in Dalbeattie "Granite," 171.
Magnetite-plagioclase rocks of Transvaal, A. K. Wells, 144.
Malvernian Hornblendes, A. Brammall and J. G. C. Leech, 286.
Matley C. A., Basal Complex in Jamaica, 331.
Mesolithic Settlement of Northern Europe, J. G. D. Clark, 327.
Mespilocrinus depressus sp. nov., 409.

Meteoric Stones, from S. Australia, L. J. Spencer, 285.
Miller, W. J., Physical Geology, 189.
Mineralogical Society, 143, 285, 328.
Mineralogy, E. H. Kraus, W. F. Hunt, and L. S. Ramsdell, 429.
Minerals, Book of, A. C. Hawkins, 141.
— for Beginners, G. S. English, 240.
Molasse Sandstones, A. von Moos, 189.
Monzonitic Series of the Newry Complex, D. L. Reynolds, 337.
Moos, A. von, Molasse Sandstone, 189.
Morven meteorite, New Zealand, C. O. Hutton, 143.
Moy-Thomas, J. A., Carboniferous Cochliodont, *Helodus simplex*, 488.

NEL, L. T., Geology of Klerksdorp-Ventersdorp Area, 191.
Newry Igneous Complex, D. L. Reynolds, 337.
— — — E. B. Bailey, 267.
New Zealand, Ordovician Rocks of, W. N. Benson and R. A. Keble, 241.
— — Spilitic Rocks in, J. A. Bartrum, 414.
Nockolds, S. R., Contrasted Differentiation, 529.
Norin, R., Swedish Basalts, 378.
North Sea, Petrology of, J. A. Baak, 283.
North Wales (British Regional Geology), B. Smith and T. N. George, 141.
— — Coalfield, fish remains, Alan Wood, 781.

OAKLEY, K. P., Ordovician Species of *Chaetetes*, 440.
Oncograptus, Structure of, O. M. B. Bulman, 271.
Ordovician Rocks, New Zealand, W. N. Benson and R. A. Keble, 241.
— Species of *Chaetetes*, K. P. Oakley, 440.
Orthoceras ungavaense sp. nov., 298.
Osteolepis, Dermal Ethmoid Shield of, T. S. Westoll, 157.

PACHYLOCRINUS dunlopi sp. nov., 401.
— *tielensis* sp. nov., 399.
Palestine, Geology of, G. S. Blake 239.
Paradoxides Beds of Öland, A. H. Westergård, 431.
Parkinson, J., Petrology of Gadabursi, British Somaliland, 365.
— — Rift Valley Impressions, 383.
Petrographic Nomenclature, A. K. Wells, 319.
Petrology, Regional, of the Southern North Sea, J. A. Baak, 283.
Photo-Micrography, Practical, J. E. Barnard and F. V. Welch, 427.
Physical Geology, W. J. Miller, 189.
Pichamuthu, C. S., Bababudanite from Mysore, India, 39.
— — Bababudanite, 335.
Plagioclase Felspars, Effects of Heat on Optical Orientation of, C. T. Barber, 286.
— — zoning in, E. S. Hills, 49.
Platinum Metals, 378.
Potash-felspars, Unusual Twin-laws in, J. L. E. Drugman, 329.
Pre-Cambrian of the Canadian Shield, the late R. W. Brock, 119.
— — Intrusives, Heavy Accessories of certain, E. L. Bruce and W. Jewitt, 193.
Psilomelane, Pyrolusite, and Hollandite, X-ray Studies in, G. Vaux, 286.
Pulfrey, W., Geology of the Kavirondo District, Kenya, 26.
Purbeck Fault, R. M. Brydone, 329.
— — and Ridgeway Faults, Dorset, W. J. Arkell, 56, 97.

QUATERNARY Research, International Association for, 240.

RAISED Beach at Brighton, the late B. Smith, 423.
Rao, B. Rama, On Bababudanite, 192.
Read, H. H., Dalradian Rocks of the Banffshire Coast, 468.
— — Rutley's Mineralogy, 555.
Reynolds, D. L., The Two Monzonitic Series, Newry Complex, 337.
— — Augite-Biotite-Diorite of the Newry Complex, 560.
— — Transfusion of quartzite, 559.
Rhaphidograptus, a new Graptolite Genus, O. M. B. Bulman, 19.
River Profiles and Denudation-Chronology, S. W. Wooldridge and J. F. Kirkaldy, 1.
— — — — J. Hanson-Lowe, 287.
Rift Valley Impressions, S. J. Shand, 307.
— — — J. Parkinson, 383.
Road Aggregates, B. H. Knight, 427.

Royal Scottish Museum, Catalogue of Type Fossils, 427.
Rutley's Mineralogy, H. H. Read, 555.

SALTERELLA, So-called, from Cambrian of Australia, L. F. Spath, 433.
Scotland, Midland Valley of (Brit. Regional Geology), M. Macgregor and A. G. MacGregor, 528.
Scrivenor, J. B., Laterite, 432.
Shand, S. J., Definition of Augite-Biotite-Diorite, 479.
— — Rift Valley Impressions, 307.
Simpson, H. H., *Anthraconauta phillipsi* in the Denbighshire Coalfield, 278.
Slieve Gallion, Age of Igneous Rocks of, J. J. Hartley, 226.
Smith, B., the late, Raised Beach at Brighton, 423.
— — — Underground Water Supply, 325.
— H. G., The South Hill Lamprophyre, Jersey, 87.
Soda-amphibole, from Mysore, India, C. S. Pichamuthu, 39.
Soils of Western Australia, D. Carroll, 503.
South-West England (British Regional Geology), H. Dewey, 45.
Spath, L. F., Ammonite Terminology, 334.
— — So-called *Salterella* from Australia, 433.
Spencer, L. J., Recently deceased Mineralogists, 286.
— — Tenham Meteoritic Shower of 1870, 328.
— — Two new Meteoric Stones from S. Australia, 285.
Spilitic Rocks, New Zealand, J. A. Bartrum, 414.
Spiral Concretions and Boring Organisms, L. Dryden, 47.
Spitzbergen, Geology of, H. Frebold, 92.
Spyroceras wordiei sp. nov., 301.
Stratigraphical Palaeontology, R. Wedekind, 238.
Swedish Basalts, R. Norin, 378.
Symplectite-bearing Nodules, H. I. Drever, 448.

TECTONIC Essays, Mainly Alpine, E. B. Bailey, 94.
Tectonics of the Purbeck and Ridgeway Faults, Dorset, W. J. Arkell, 56.
Tenham Meteoritic Shower of 1870, L. J. Spencer, 328.
Tertiary Faunas, A. M. Davies, 326.
— Dykes of Craignish, Argyll, A. Allison, 73.
Thames Valley, Late Glacial Episode, J. P. T. Burchell, 91.
Tilley, C. E., Enderbite, a New Member of the Charnockite Series, 312.
— — Eulysites, and related rock types, 144.
— — Paragenesis of Kyanite-eclogites, 328.
Transfusion of Quartz xenoliths, A. Holmes, 559.
— of quartzite, D. L. Reynolds, 559.
Trechmann, C. T., Basal Complex, Jamaica, 251, 382.
Tribrachiocrinus caledonicus sp. nov., 402.
Trueman, A. E., Coal Measures of Scotland, 287.
Twenhofel, W. H., Invertebrate Palaeontology, 326.

ULOCRINUS doliolus sp. nov., 404.

VAUX, G., X-ray studies on Psilomelane, Pyrolusite, and Hollandite, 286.
Vertebrate Fossils from Ceylon, P. E. P. Deraniyagala, 316.

WATER Supply, Underground, B. Smith, 325.
Wayland, E. J., Geology of Kavirondo, 330.
Wedekind, R., Stratigraphical Palaeontology, 238.
Wells, A. K., Magnetite-plagioclase rocks of Transvaal, 144.
— — Petrographic Nomenclature, 319.
Westergård, A. H., *Paradoxides oelandicus* Beds of Öland, 431.
Westoll, T. S., Dermal Ethmoid Shield of *Osteolepis*, 157.
Whitehouse, F. W., Cambrian Faunas, Australia, 430.
Williamson, W. O., Minor Intrusions of Glen Shee, 145.
Wood, A., Fish Remains from N. Wales Coalfield, 481.
Woodocrinus gravis sp. nov., 396.
— *liddesdalensis* sp. nov., 387.
— *whytei* sp. nov., 394.

Wooldridge, S. W., River Profiles in S. England, 1.
Wright, J., New Scottish Carboniferous Crinoids, 385.

XENOLITHIC Pegmatite in Dalbeattie "Granite", M. MacGregor, 171.

ZIRCON, Outgrowths on, J. A. Butterfield, 511.
Zoning in Plagioclase Felspars, E. S. Hills, 49.

Stephen Austin and Sons, Ltd., Printers, Hertford.